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SCIENCE

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War on Weeds

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MORE WORK ON HERBICIDES and more in the way of scientific and practical achievement with herbicides has taken place in the past decade than at any time in history. No doubt the urgent need for increased food production, coupled with the drastic shortage of farm labor, stimulated interest in weed control.

Significance of Herbicides

A weed (*18*) may be defined as an undesirable plant or "a plant out of place." Weeds compete for a place in the sun by occupying space. They also compete for soil nutrients and thereby reduce not only the yield but also the quality of farm crops. Both woody and herbaceous plants may be weeds, and they can cause losses in many and devious ways. Most virus diseases of plants are spread by insects and in every known case weeds serve as hosts for the insect vector and may also harbor the virus pathogen. Many fungus and bacterial diseases of plants overwinter on, or are harbored by, weeds (e.g. downy mildew of lettuce winters on wild sunflower and thistles). Economic insects are frequently harbored on weeds, where the weed fits into the insect's life cycle (cotton aphid, potato flea beetle, red spider). The winter phases of the life cycles of the leaf hopper insects, which carry curly-top virus to sugar beets and yellow blight to tomatoes in California, are spent mainly on thistles. Weed control will become more and more important as more is known about the disease and insect pests of farm crops.

Weeds function as an unseen tax on the crop harvest. For example, it is estimated that losses from weeds in California total about $60,000,000 annually. According to Taylor (*25*), weeds rob farmers in the United States of $3,000,000,000 a year. From this, the economic importance of weed control cannot be questioned. The weeding operation, especially where vegetables like onions and carrots are concerned, can comprise 30 per cent of the cost of production. The hand labor involved in the first weeding of onions and carrots is always very tedious, requiring adequate, careful, and timely work costing about $30 an acre. Here an inexpensive, rapid method of killing weeds is needed.

Certain weeds are so efficient as competitors of the food and forage crops that they have thwarted the efforts of man to control them by any means. These weeds are called "noxious," and it is of interest to know that most of the noxious weeds (Canada thistle, sow thistle, Russian thistle, artichoke thistle, wild mustard, Russian knapweed, corn cockle (?), English plantain, wild oats, wild morning-glory, quack grass, etc.) are aliens or exotic. The water hyacinth which now clogs the fresh-water streams and lakes in subtropical America originally came from Japan.

Many weeds persist for long periods of time in the soil when buried in the plowing operation. Each cultivation usually starts off a new crop of weeds. While there are numerous species (annual, biennial, or perennial in habit), only a relatively few are of serious economic importance for any one crop. Annuals, in passing through their complete cycle back to seed in one season, are vulnerable to herbicides, especially when small. For the perennials the situation is different because the herbicide must be capable of reaching and killing the underground parts if it is to be successful.

The importance of weed control led several years ago to the organization of the Western Weed Control Conference, consisting of all weed-control officials in 11 Pacific slope states. Recently, a North Central States Weed Control Conference, composed of 13 states, was organized. Its research committee has suggested a uniform plan of experimentation on 2,4-dichlorophenoxyacetic acid (2,4-D) for 1946 based on the 1945 program. Apparently the remarkable number of new herbicides developed during the past decade (sulfuric acid, Sinox, ammonium sulfamate, sodium pentachlorophenate, oils, 2,4-D, 2,4,5-T, Sizz-weeder, mechanical shredder, 2,4-dinitro-6-sec-butyl phenol, etc.) has stimulated an organized attack on weeds that will bear watching.

For convenience, herbicides can be divided into several groups: (1) soil sterilants, illustrated by

sodium arsenite, ammonium thiocyanate, borax or borate ores, carbon bisulphide, chloropicrin, and sodium chloride; (2) nonselective contact sprays, such as the numerous nonselective oil, acid, and salt derivatives which kill all vegetation down to earth; (3) selective sprays, illustrated by sulfuric acid, oils, and Sinox, which wilt down most broadleaf weeds, but leave grains, flax, and grasses virtually unaffected; (4) translocated poisons, illustrated by arsenic trioxide, arsenic trichloride, sodium chlorate, ammonium sulfamate; (5) flame thrower, illustrated by the Sizz-weeder, a machine designed especially for weeding row crops; (6) growth regulators or hormones, such as 2,4-D and 2,4,5-T—substances which in relatively minute quantities stimulate abnormal growth followed by death of plants; and (7) miscellaneous devices, including a machine for moving and crushing the water hyacinth, soil covers or barriers to suffocate weed growth, cover crops, etc.

History

The principle of selective weed killing with chemical sprays has been known for over a half century (*21*). A concentrated iron-sulfate solution was used against weeds in cereals for many years both in Europe and America and with some success. Bolley (*3*), in North Dakota, demonstrated that iron sulfate could be used to kill some weeds in cereals. Rabate (*20*) opened a new era by employing dilute sulfuric acid, but little came from his work until later.

Of the various materials, the soil sterilants were probably the earliest herbicides used by man. Many salts of acids, when applied to the soil in sufficient quantity, will kill all plant growth. The soil is thereby rendered unfit for growing plants until the chemical has been leached out by rains. For killing deep-rooted perennials, 250 pounds of table salt, 15 to 30 pounds of borax, and 3 to 4 pounds of sodium arsenite are required to treat one square rod of area. Many nonselective contact sprays contain sodium arsenite alone or in combination with sodium chlorate. This, however, is very poisonous to livestock, is expensive, and is a fire or explosion hazard. Aside from soil sterilants and nonselective contact sprays, most herbicides used today are new.

Sulfuric Acid

Ball and French (*1*) were the first to point out the possibility of using dilute sulfuric acid for killing weeds among young onions. Newhall, *et al.* (*19*) extended this work and demonstrated that, when properly applied, sulfuric acid functioned as an inexpensive, rapid method of killing weeds. One gallon of cheap ($.35) sulfuric acid added to 50 gallons of water made enough solution to spray one-half acre of onions. Weeding time and expense were cut to one-fourth by this method. Most weeds are killed, but certain ones, like grasses of upright growth or lamb's-quarters and purslane which have waxy bloom, are not easily wet by the acid and may not be killed.

Sinox

Sinox (sodium-dinitro-ortho-cresylate), a coal tar derivative in the form of yellow dye, was first used as a selective herbicide in France in 1933 and as a weed spray in the United States in 1938. It is also an insecticide and pollenicide. This herbicide has been used in extensive field trials in many places, including California (*27*), North Dakota (*10*), Montana (*15*) and Canada (*32*). Westgate and Raynor (*27*) obtained successful results in cereals and flax with spray rigs mounted on trucks and on airplanes. For airplane application the cost was about a dollar more than for ground rigs, averaging $3.65 an acre for controlling wild mustard and $4.65 for wild radish, fireweed, and yellow star thistle. The dosage of 1 gallon of Sinox to 120 gallons of water was applied at the rate of 80 to 100 gallons per acre on mustard when the weed was 3 to 7 inches high and had 3 to 7 leaves. Established transplanted onions were also sprayed with safety until they were approximately 10 inches high. Common dandelion, common plantain, and crab grass were successfully controlled in bluegrass lawns.

Sinox kills only the broad-leaved annual weeds, including ragweed, and has little effect on grasses. The young seedling weeds are most easily killed. Spraying with Sinox, Helgeson and Gebracht (*10*) increased the yields of flax by as much as 232 per cent. In their report on three seasons work, Litzenberger, *et al.* (*15*) obtained yield increases up to 264 per cent. They cautioned that flax and peas should never be sprayed before reaching 3 inches and never after bud formation. Small grains may be sprayed when taller, but treatment should be made before they reach jointing stage.

Schwendiman, *et al.* (*22*) studied the effects of Sinox on legume seedlings, weeds, and crop yields in Wisconsin and reported that Sinox killed 0 to 70 per cent of alfalfa and red clover up to 4 weeks of age, but that these plants developed a high resistance to this herbicide when 4 to 6 weeks of age.

Sinox, together with ammonium sulfate as an activator, has been used by Bonde and Schultz (*4*) and others for killing the tops and thereby controlling the late blight tuber rot of potatoes. Sinox spray also aids in harvesting and improving the quality of potatoes for early market, and enables growers to harvest the crop before the onset of freezing weather.

Ammonium Sulfamate

Ammonium sulfamate is technically a contact and translocation herbicide. For about 60 years it was

known as a laboratory curiosity in chemistry. Originally it was sometimes used for fireproofing wood. Recently Du Pont chemists found an economical way to produce this in large quantities. In 1941 (*11*) it was found to be a more suitable herbicide than sodium chlorate for eradicating chokecherry, the wild host of the yellow-red or "X" disease of peach. It is also excellent for poison ivy, but was not satisfactory for killing water hyacinth (*7*). For spraying, about three-fourths of a pound of this salt is dissolved in a gallon of water and applied at the rate of from 1 to 3 gallons per 100 square feet of weed growth area. Ammonium sulfamate is nonpoisonous to animals, free from fire hazard, and does not leave the soil sterile for more than a short time. In fact, it contains a high percentage of fixed nitrogen which enriches the soil. Aside from its use for such special weeds as chokecherry and poison ivy or small areas of noxious perennial weeds where its nonselective action is tolerated, the cost of "Ammate" is too high to allow it to be used generally on large areas.

Sodium Pentachlorophenate or "Santobrite"

Santobrite was recommended by Hirsch (*12*) at a concentration of 5 ppm for retarding growth of water hyacinth where its complete removal is not essential or in zones where other life is to be preserved, and of 80 ppm for complete elimination.

Oils

Oils have long been known to be toxic to plants. It has been only recently, however, that their value as selective weed killers has been recognized. In California and other far-western states oil sprays have been used for weeding carrots on a commercial scale since 1943 (*6*). Oils are applied full strength, undiluted, and have since been widely used in several central and eastern states, including New York (*23, 24*), Massachusetts (*13*), Michigan (*8*), Wisconsin (*26*), and others. Kerosene was reported by Loomis and Noecker (*16*) and Litzenberger and Post (*14*) as a selective spray for dandelions in lawns. According to Warren (*26*), all important annual weeds in Wisconsin carrot fields, with the exception of ragweed, are easily killed by oil spray. In perennial weeds, such as quack grass and Canada thistle, the tops are burned severely, but the roots are not killed. One oil spray of carrots costs about one-half that of hand weeding, or about $13 an acre.

Sweet, *et al.* (*23*) report that the plants tolerant to oil sprays are members of the Umbelliferae family—carrots, celeriac, taprooted parsley, and celery. Some tolerant weeds are ragweed, wild carrot, galensoga, and a few grasses.

Young (*29*) reported that oils are translocated in onions and potatoes, are located principally between parenchyma cells, and persist in the tissues several months. He suspected toxic substances in the oil as one cause of death and mentioned physical suffocation as another.

Sweet, *et al.* (*24*) consider that the general types of injury possible from petroleum products are "chronic" and "acute." Chronic injury is associated with heavy oils, such as lubricating and motor oil. It is slow in action and kills practically all plants including carrots, due to "suffocation" of the tissues. Acute injury is due to chemical composition of the oil and is correlated with toxic aromatic content. It often acts within an hour or two after it has been applied. Carrots are rather tolerant of aromatic compounds, whereas most other vegetables and weeds are not. It is on this basis that oils can be used as selective weed killers. To avoid chronic injury only light-weight oils are used. The best are: (1) dry-cleaning fluids sold as Stoddard Solvent and (2) kerosenes that have 12 to 15 per cent aromatics. The important thing in application is thorough, uniform coverage of weeds when the carrots have 2 to 4 "true" or "fern" leaves and preferably before the weeds are over 3 inches tall. Due to oil absorption and slow dissipation, only one spray can be used for bunching carrots, as a month must elapse before harvest to get rid of the oil absorbed.

2,4-Dichlorophenoxyacetic Acid

The outstanding sensation concerning weed killers in 1944 was the public announcement of growth-regulating substances or plant hormones as herbicides. Work of a preliminary nature, started in July and published in August 1944 (*9*), demonstrated that 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) were selective herbicides. Credit for the original discovery of the chemical itself goes to Zimmerman and Hitchcock (*30*), and for methods of handling it in work on plants, to Mitchell and Hamner (*17*).

Because plant hormones operate on the principle of growth regulation rather than caustic action or poisoning, this discovery marks a new departure in the history of herbicides and promises in the future to prove particularly rewarding in special cases. The first tests (*9*) demonstrated that 1,000 ppm and 500 ppm of 2,4-D were effective in killing perennial bindweed (*Convolvulus arvensis* L.) on nursery fruit trees. Similar concentrations of 2,4,5-T also seemed to possess almost equally effective herbicidal properties against this weed. When it is remembered that black bindweed is considered the number one weed enemy of crops (herbaceous and woody) and that the quan-

tity of material is measured in parts per million rather than in pounds or gallons, the sensation created by the discovery of 2,4-D can be readily understood.

The first results (*33*) were so remarkable that tests by a multitude of public and private agencies were conducted throughout the Nation (*34*), and in England (*2*) in 1945. This new departure is not the whole story of recent developments of scientific and practical interest on herbicides but only the beginning.

The most interesting characteristic of plant hormones is the small dosages needed to be effective. At 10 ppm, more or less, hormones in general produce beneficial effects. When increased to between 100 and 1,000 ppm, the 2,4-D hormone stimulates abnormal growth. The usual application is one-fourth to one-half ounce per square rod. Therefore, one pound incorporated into a spray would cover from 32 to 64 square rods compared with one-third to one-fourth square rods for such chemicals as sodium arsenite, sodium chlorate, and ammonium sulfamate. Although usually applied in water sprays, hormones may also be incorporated into dusts and aerosols.

Under favorable conditions 2,4-D applied to foliage migrates and causes death of entire deep root systems. Other important characteristics of 2,4-D are that it is noncorrosive, nonirritating to skin, and nonexplosive. Feeding trials with animals have been conducted without adverse effect. Some investigators have consumed the chemical and suffered no ill effects. The action of 2,4-D is highly selective. It attacks most broadleaf plants, but there are exceptions. Tomatoes are killed by 100 ppm, whereas Kentucky bluegrass has withstood 10,000 ppm. While disadvantageous in some respects, this property may be a great advantage in others. The fact that it is used in such dilute concentrations makes it relatively inexpensive, and it should not cost over $5 to spray one acre.

The work on 2,4-D is so new that only a few general principles will be stated at this time: (1) It is most effective on young plants in periods of rapid growth; (2) it acts slowly, requiring a month to produce killing action; (3) it appears to be most effective when applied to plants growing in moist soil; (4) eradicative action seems to proceed more rapidly in sun than in shade; (5) it should not be applied within 4 hours of a rain. For details see Willard (*34*).

People with weed control problems in 1946 in farm crops, nurseries, gardens, lawns, or waterways will be greeted with an array of over 30 preparations of 2,4-D (in acid, salt, or ester form) on the market. These materials are put up as powders, liquids, pastes, and tablets. One chemical concern prepared a dust form in 1945. Aerosol carriers are also a possibility in 1946. The preparations may contain all the way from about 10 to 100 per cent of active ingredient. It is still too early to make general recommendations on the use of 2,4-D. However, in the special case of the water hyacinth there is very little choice about using a hormone herbicide, since poisonous chemicals are ruled out.

Sizz-weeder

The Sizz-weeder, or Flame Cultivator, was first tried out on cotton in Mississippi (*31*) and on some other crops in New Jersey in 1944. In 1945 it was tested for killing weeds in corn and other row crops in New York (*28*). This machine is designed to produce a hot-air-blast flame to cause dehydration and destruction of weeds and grasses while leaving the desired crop unharmed. The burners are adjustable in three planes, and the principle of flame weeding is the application of heat at any time when the crop plant to be cultivated has more fiber content (heat resistance) than the weed growths possess. This method, like that of applying herbicides in sprays, has advantages, since it eliminates cultivation which continually brings weed seeds to the soil surface for germination.

Experiments to date indicate that (1) weeds 3 or 4 inches in height can be successfully killed in row corn 6 inches high or higher without seriously damaging the corn; (2) many large weeds, although not killed, are arrested in growth; (3) results on soybeans, peas, beans, cabbage, and spinach were discouraging; (4) two burnings spaced at least a few hours apart are even more effective than four burnings in immediate succession. Some difficulties were experienced, but these should be corrected with time.

Mechanical Weeder

Gowandloch (*7*) reported on the use of a mechanical weeder for combating the water hyacinth in Louisiana. An earlier device consisted of a conveyor to deposit the water hyacinth on stream banks to perish. This craft is equipped with crushing machinery so that the hyacinth plants are incapable of reproduction when returned to the water.

Crafts (*5*) has recently announced another new herbicide, 2,4-dinitro-6-sec-butyl phenol, which possesses some advantages over chemicals like sodium arsenite and sodium chlorate.

THE FUTURE

It is not necessary to point out the possibilities of scientific development of herbicides in the future. Of all the work to be done along the weed-control front, there is no doubt that in the future hormones like 2,4-D will receive adequate attention, although much will continue to be done all along the line of attack on weeds employing chemicals and machines as herbicides.

(*See page 492 for references.*)

Plant Growth Regulators

Special Projects Division, Chemical Warfare Service

Camp Detrick, Maryland

THE USE OF PLANT GROWTH REGULATORS as herbicides is a subject of great interest to most individuals who deal with plant life. Recently this interest has increased rapidly, if one is to judge by the large number of articles on 2,4-D (2,4-dichlorophenoxyacetic acid) appearing in scientific journals as well as in lay publications.

During the war extensive tests on the use of plant growth regulators were conducted by the Special Projects Division, Chemical Warfare Service, at Camp Detrick, Maryland. Certain phases of this work were performed under contract by members of the Bureau of Plant Industry, U. S. Department of Agriculture, and the Department of Chemistry, Ohio State University. Results of these investigations will be published in part in the June issue of *Botanical Gazette*. Other papers on the subject will appear from time to time in other journals. A brief summary of the results of this work is given here.

Over a thousand compounds were prepared and tested. Since it was impractical to test all potential plant growth regulators on a great number of plants, several screening procedures were devised which permitted the rapid and accurate evaluation of the physiological activity of each compound. The most important screening tests were (a) measurement of inhibition of root elongation of germinating corn seed, (b) measurement of inhibition of tissue production of red kidney beans when a single droplet of the substance, dissolved in water or oil, was placed on the midrib of the primary leaf. The inhibition caused by the chemical was compared with that produced by 2,4-D. Compounds which displayed a high degree of activity in the screening tests were then tested on a number of monocotyledonous and dicotyledonous plants in the greenhouse and in the field. The compounds prepared and tested were functional derivatives of phenoxyacetic, benzoic, naphthoic, phthalic, sulfamic, carbamic, cinchoninic, and picolinic acids and a host of other organic chemicals.

In a study of methods of application it was discovered that the application of like amounts of growth regulator to the soil as a solid and to the aerial portions of plants in the form of aqueous or nonaqueous sprays produced widely differing effects, the herbicide being many times more effective when applied in a spray.

Comparatively low concentrations of growth regulators applied to the soil prevented seed germination, but when the solid chemical was applied to the soil as a contaminant, the dosage required to kill growing plants increased with increasing age of the plants at the time of application. The same age relationship was evident when the regulator was applied to the aerial portions of the plants in the form of a spray.

The persistence of these growth regulators in the soil was also studied. It was found that 2,4-D did not persist in soil for more than 80 days and isopropyl N-phenylcarbamate seemed to disappear within 60 days.

In soil-leaching experiments 2,4-D was recovered in the leachate.

Frequently compounds were encountered which were very difficult to dissolve in the solvent selected, and recourse was made to the use of cosolvents. Tributyl phosphate proved to be the most satisfactory cosolvent and was found to be suitable for preparing high concentrations of herbicides in oil solution. The carbowaxes (polyethylene glycols) were found to be suitable cosolvents for the preparation of aqueous solutions, in which they also acted as wetting agents or spreaders.

Since it had been shown that several hours are required for plants to absorb maximum amounts of 2,4-D sprayed on their leaves, an investigation was undertaken to determine to what extent heavy rainfall would remove this compound and reduce its effectiveness as a herbicide. Results show that when the herbicide was applied in oil solution, an immediate heavy rain caused no diminution in response to the herbicide, as the drops of rain appeared to be shed from the oil-covered leaves without the removal of the oil solution. When aqueous solutions of the herbicide were used, a heavy rainfall within 24 hours reduced the effectiveness of the herbicide to a marked degree. Thus, the value of oil as a solvent in herbicide applications just prior to rain or in regions of high rainfall is indicated. Another advantage of oil solutions as herbicides is the contact injury produced by tributyl phosphate, which is generally used as a cosolvent.

Studies on the mode of entry and translocation of regulators indicate that the stomata may be unimportant as a portal of entry. Young *Nasturtium* and *Coleus* plants were selected for experimentation, since they have stomata only on the lower surfaces of the leaves. Some plants were sprayed in such a manner that only the upper leaf surfaces were exposed, and other plants so that only the lower surfaces were exposed. The resulting degree of inhibition was about the same, regardless of the particular leaf surface

sprayed. However, when plants are exposed to volatile growth regulators or aerosols, stomata probably play a more important role.

Often 2,4-D enters the leaf with great rapidity. On warm, sunny days young broadleaf plants sprayed with this compound may exhibit epinasty and stem curvature within one hour after treatment.

It was originally believed that there might be a high degree of compound-crop specificity. This was found to be true to a limited extent. In general, the compounds were more toxic to broadleaf plants than to grasses. One group of compounds, however—the carbamic acid derivatives and, in particular, isopropyl phenylcarbamate—was more toxic to cereals than to broadleaf plants. This confirms the results of British investigators (*1*). Among the broadleaf plants only one instance of compound-crop specificity was noted. The compound, 2,4,5-trichlorophenoxyacetic acid, and its derivatives were highly inhibitory to Irish potatoes, while all the other phenoxyacetic acids and derivatives tested on this crop had little effect.

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Obituary

John Campbell Merriam

1869-1945

Dr. John Campbell Merriam, distinguished paleontologist, died in Oakland, California, on 30 October 1945. He had just passed his seventy-sixth birthday. Since his retirement from the presidency of the Carnegie Institution of Washington, which office he held for 18 years, Dr. Merriam had continued his writing and scientific study on the Pacific Coast, spending much of his time at the California Institute of Technology. In 1943 he became consultant and lecturer at the University of Oregon, where he was associated with the Departments of Geology and Anthropology. These were his last scientific interests before his health failed.

Born in Hopkinson, Iowa, Merriam received his early education at home and in the schools of that state. It was here that he saw his first fossils—the Paleozoic invertebrates he collected not far from his father's home. After taking a bachelor's degree at Lenox College, Iowa, he came to the University of California to study geology under Joseph Le Conte and botany under E. L. Greene. During this period he was an assistant in mineralogy. As was customary in those days, Merriam went to Munich for advanced study, receiving his doctorate at the University under Karl von Zittel. His dissertation related to mosasaurs from the Kansas chalk. On his return to the University of California in 1894 he taught and conducted research in invertebrate paleontology.

However, vertebrate paleontology claimed his major interest, and there followed published accounts by him and by his students on cave explorations and early man in California, Triassic ichthyosaurs and thalattosaurs, and on the geology of the John Day basin. He later enlisted the aid of Miss Annie M. Alexander in his research, and the generous response of this fine and steadfast patroness of paleontology and zoology was an important factor in permitting him to achieve success. Even before completion of the work on fossil reptiles his interest turned more strongly toward fossil mammals and early human history. Among his many papers, those which relate to western Tertiary faunas, correlation studies, and to the deposits and faunas of Rancho La Brea may be cited as among his most significant contributions. They were published for the most part in his productive period of research at the University from about 1900 to 1919. These were the years when a number of students came under his influence, and many men receiving instruction from him were subsequently to find responsible posts in science and industry.

During this time he became increasingly active in the affairs of the University and of the community. He was particularly interested in promoting research and in furthering the publication of original investigations. In 1912 President Benjamin Ide Wheeler appointed him chairman of a newly formed Department of Paleontology. At the time of World War I he saw the urgency of a national defense program. He became chairman of the Research Committee, California State Council of Defense, which office he held from 1917 to 1920. In 1919 he was chairman of the National Research Council. Later, in 1920, he became dean of the faculties at the University.

Although considered a candidate for the presidency of the University of California during the period which followed the retirement of Dr. Wheeler, Merriam accepted the presidency of the Carnegie Insti-

tion of Washington. It was his belief that, rather than continue his career as paleontologist, he should serve science broadly and more effectively by becoming head of a great research foundation.

During the next 18 years he was occupied with the innumerable tasks which face an executive of a large organization. This period of service is perhaps most noteworthy because of a certain centralization of the activities of the Carnegie Institution of Washington, although he enlarged the group of research associates who were affiliated with other institutions of learning. He gave stimulus to publication of scientific results and to a dissemination of knowledge gained by eminent scholars of the Institution staff through popular articles, lectures, and demonstrations. He was responsible for the establishment of a Seismological Laboratory and a program of seismological research on the Pacific Coast as a cooperative plan of the Institution and the California Institute of Technology. He was also much interested in the program of archaeological research in southern Mexico and Guatemala. Later, the investigation included studies of early man in America and Asia. Paleontology and paleobotany likewise received added support.

All his activities were by no means confined to the Carnegie Institution of Washington. Dr. Merriam continued for a time as regent of the Smithsonian Institution. He fostered the unique educational features of some of our National Parks. He was president of the executive committee of the Pan-American Institute of Geography and History from 1935 to 1938. He carried over from his university days his association with the Save-the-Redwoods League and for 24 years continued as its president until his retirement from that office in 1944. These were the years when he brought to publication most of the articles and essays of a more general and philosophical nature. His broad interest in the human values derived from education and research led to the publication of his book, *The living past.* On his retirement in 1938, the Carnegie Institution reprinted all his papers and addresses and published likewise an appreciation volume entitled: *Cooperation in research by staff members and research associates.*

Articles of general scope and his second book, *The garment of God,* were published after his retirement. He continued to concern himself with the National Parks of the West and with the State Parks of Oregon. Largely through his activity, the group known as the John Day Associates was established with the purpose of conserving the famous fossil beds of the John Day basin and of developing public interest in the geological story so clearly told by the rocks and fossils of the region.

Some paleontologists never weary, even in old age, in their devotion to the study of fossils. In the later period of his life, however, Merriam never again applied himself to this kind of research, being content to let others carry on. His eminence in science was recognized, and acknowledged in the usual way. Honorary degrees were awarded him by many universities. He was a member of the Society of Vertebrate Paleontology, president of the Paleontological Society in 1910, president of the Geological Society of America in 1919, president of the American Society of Naturalists in 1936, and a member of the National Academy of Sciences, Academia Nacional de Ciencias Antonio Alzate de Mexico, and Sociedad de Geografía e Historia de Guatemala. A gold medal was awarded him by the American Institute, New York.

Thus, Merriam's interests were not only in paleontology. During his lifetime he was also educator, conservationist, administrator, and philosopher. By nature not genial, but rather grave and distant, he nevertheless left the impress of his thought on students and on men and women in many walks of life. By them he will be long remembered.

CHESTER STOCK
California Institute of Technology

Technical Papers

Use of 2,4-Dichlorophenoxyacetic Acid as a Selective Herbicide in the Tropics

J. VAN OVERBEEK and ISMAEL VÉLEZ

Institute of Tropical Agriculture, Mayagüez, Puerto Rico

During the past year extensive trials were conducted on the use of 2,4-dichlorophenoxyacetic acid[1] as a selective herbicide for tropical crops in Puerto Rico. Its most beneficial use is in the sugar-cane culture, but in coffee plantations also it promises to be of considerable importance. While many of the major weeds associated with these crops are highly susceptible to 2,4-D, neither sugar cane nor the coffee plant have shown any adverse effects of sprays up to 0.3 per cent concentration.

It was found that weeds could be divided into four classes in regard to their sensitivity[2] to 2,4-D:

Class I consists of a group of highly sensitive plants, represented by Curve I of Fig. 1. *Commelina*, one of the most serious sugar-cane weeds in moist lands, is the main representative of this group. A single treatment with 0.05 per cent of 2,4-D at a cost which is often as low as 50 cents per acre[3] gave sufficient control. Several species of *Ipomea*, and *Stizolobium pruritum* (Wight) Piper (the *pica pica* feared by sugar cane workers on account of its stinging hairs), fall in the same sensitivity class, as does *Urera baccifera* (L.) Gaud., the giant nettle, which is a major pest in coffee plantations. Other weeds belonging to this class are: *Bidens cynapiifolia*, H. B. K., *Cissus sicyoides* L., *Cleome gynandra* L., *Clerodendrum fragans* Vent., *Momordica charantia* L.

Class II is a group of weeds characterized by Curve II and represented by several species of *Amaranthus* (pigweed). To this group also belong: *Achyranthes sessilis* (L.) Steud., *Kallstroemia caribaea* Rydgerg., *Poinsettia heterophylla* (L.) Kl. Garcke., *Ricinus communis* L., *Solanum torvum* L., *Synedrella nodiflora* (L.) Gaertn., *Teramnus uncinatus* (L.) Sw., and *Wedelia trilobata* (L.) Hitch.

Class III is a group of weeds characterized by Curve III, the major representative being *Cyperus rotundus* L. (nutgrass). Sufficient control was usually obtained with 0.15 per cent sprays. Other plants belonging to the same group are: *Chamaescyce* spp., *Crotolaria retusa* L., *Malachra capitata* L., *Portulaca oleracea* L., *Sida* spp., *Trianthema portulacastrum* L., and *Vernonia cinerea* (L.) Less.

Class IV comprises a group of plants which are relatively insensitive to 2,4-D sprays. Grasses are the most typical representatives of this group. However, the following nongramineous plants were also found to be resistant: *Aeschynomene* spp., *Aloe vulgaris* L., *Bradburya pubescens* (Benth) Kunth, *Bryophyllum pinnatum* (Lam.) Kurtz., *Chamaecrista* spp., *Dieffenbachia seguine* (Jacq.) Schott., *Emelista tora* (L.) Britton and Rose, *Indigofera suffructicosa* Mill., *Jussiaea angustifolia* Lam., *Meibomia supina* (Sw.) Britton, *Mimosa pudica* L., *Opuntia dillenii* (Kerr-Gawl) Haw., *Persicaria punctata* (Ell) Small, *Petiveria alliacea* L., *Urena lobata* L., *Xanthoxalis corniculata* (L.) Small.

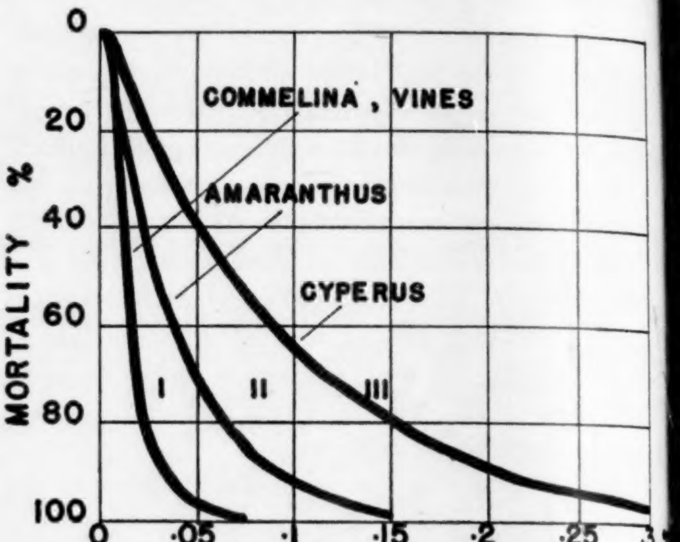

FIG. 1

The action of 2,4-D differs considerably from that of weed killers of the conventional type. The latter act rapidly, have a burning action on the foliage, but often do not damage the growing point sufficiently to prevent regeneration. On the other hand, 2,4-D penetrates inside the plant and without the typical leaf-burning destroys the growing regions in the course of a few weeks. In *Commelina* the growing point and the intercalary growth regions are destroyed. In *Cyperus* the well-protected growth region, located within the base of the leaf sheaths and 5 cm. or more below the surface of the soil, is decayed, while at the same time the leaves show no more serious outward sign of damage than yellowing.

[1] Converted into the more water-soluble ammonium salt by the addition of NH_4OH on an equimolecular basis.

[2] Applications were made to young weed plants, since it was found that mature plants are generally relatively insensitive.

[3] Cost of chemical only, applied at a rate of 50 gallons per acre. Depending upon the type of weed infestations, applications varied between 50 and 250 gallons per acre.

This preferential action on the growing region suggests that 2,4-D owes its effectiveness to competitive action with the plant's native growth-regulating substances. The fact that 2,4-D itself has definite growth-regulating properties (*1*) further strengthens this assumption.

Although in practice 2,4-D is sprayed on the surface of weeds rather than on the soil, some of it is bound to come in contact with the soil. In order to determine spray residues in soils, a test was devised which was based upon the high sensitivity of radish seedlings to 2,4-D. When radish seed was germinated on cotton soaked in 2,4-D solutions, it was found that concentrations as low as 0.1 ppm cause a striking reduction in root and hypocotyl growth in comparison to seeds germinating in water. A similar effect was found in radish seedlings germinating in soils which had been sprayed with 2,4-D. Under the conditions of our experiments 2,4-D was detectable in soils up to three weeks after 0.15 per cent solutions were sprayed directly on the soil at a rate of 300 gallons per acre, and up to five weeks when 0.3 per cent solutions were applied.

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Control of Ragweed Pollen Production With 2,4-Dichlorophenoxyacetic Acid[1]

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In surveying the selective herbicidal action of 2,4-dichlorophenoxyacetic acid, Hamner and Tukey (*2*) found that ragweed was among the more sensitive of the common weeds. Since ragweed is probably the most important cause of pollen allergy, its control is of great importance both as an economic and a public health measure. It was desirable, therefore, to investigate further the application of 2,4-D to ragweed control and to point out the practical possibilities.

In many urban areas in the East and Middle West before the war considerable effort and expense was put into campaigns to eradicate ragweed by cutting or treatment with various herbicides. The success of this means of controlling allergy due to ragweed pollen, and public interest in it, could undoubtedly be greatly increased by the availability of a cheaper, more effective method. Grigsby (*1*) has recently reported the use of several of the newer herbicidal compounds in ragweed control and has suggested that 2,4-D may be more effective. The essential requirement of any method, as Grigsby points out, is to prevent the formation or shed of pollen; but it is also desirable (1) to cause as little damage to other vegetation as possible, (2) to leave no residue toxic to animals, and (3) to require the minimum in cost of materials, time, and equipment.

[1] Journal Paper No. 646 of the New York State Agricultural Experiment Station, Cornell University, 20 September 1945.

RESULTS

Beginning on 26 July, plots 5 yards square were treated at weekly intervals in three locations where both eastern species of ragweed, *Ambrosia artemisiifolia* L. and *A. trifida* L., were growing abundantly among other common weeds. The treatments were made by water sprays of 1,000 ppm of 2,4-D containing 0.5 per cent Carbowax 1,500, as described by Mitchell and Hamner (*4*), and were applied with a 5-gallon knapsack sprayer at the rate of about 100 to 200 gallons per acre. Notes on the stage of flower development at the time of treatment and frequent observations of the effects were made to determine the latest safe time for treatment to prevent pollen formation or shed.

At the time of the first series of treatments the majority of plants had racemes varying from a few millimeters to 20–30 mm. in length. Within 24 hours these plants showed pronounced epinasty and twisting of pedicels, leaves, and stem tips. By the fourth day the twisting was more severe, growing points were enlarged, longer racemes were pendant, and a few lower leaves were chlorotic. By the fourteenth day none of the involucres had opened, and no further development of the flowers had taken place. Many plants showed extensive swelling and splitting of stem tips and the death of lower leaves. By the twenty-eighth day (23 August) the tops of about half of the smaller plants were dead, and larger plants showed typical red and yellow fall colors and were dying back from the tips. Controls at this time had developed normally and were shedding pollen.

At the time of treating the second series of plots (2 August) some of the racemes were fully developed and involucres were starting to open. Symptoms developed similar to the first treatment, and by the twenty-first day (24 August) some plants were dead, and there was no sign of pollen shed. Most of the involucres had not opened, and in those which had, the pollen sacs were dead.

At the time of the third series (10 August) most of the involucres were open, and some of the pollen sacs were mature. Eighteen days later (28 August) the younger racemes and tips of the older ones were dead, and no pollen had been shed, but at the base of the

older racemes there were empty pollen sacs and pollen could be squeezed from others. The fourth series (17 August), at the time pollen shed was starting, showed the same general symptoms by 28 August as the third treatment except that the proportion of surviving pollen sacs and the extent of shedding was greater. Though the third and fourth treatments clearly caused reduction in the amount of pollen shed, they were too late to prevent it completely. That the pollen shed from these late treatments was not altogether normal was indicated by their vacuolate condition, similar to the effect of 2,4-D on bindweed pollen (*6*). No test was made, however, of their allergenic properties.

These experiments indicated that the safest procedure would be to treat plants before the involucres are open. Limited trials with lower concentrations and more extensive experience with other weeds have indicated that concentrations lower than 1,000 ppm might be equally effective in stopping development of the flowering parts, though the response would probably be slower.

A preliminary trial was also made of a new method of treatment which shows great practical possibilities in the large-scale application of chemical agents to plants. On 6 August a test of 2,4-D with a fog machine[2] was made, in which a 1-per cent solution in SAE 30 oil was "fogged" across an area of mixed weeds at the rate of about 1 to 2 gallons per acre from the back of a truck moving 3 or 4 miles per hour. Despite unfavorable atmospheric conditions, cool and damp with updrafts, telemorphic effects were visible on ragweed up to 100 feet from the machine within 24 hours. A week later severe symptoms were found throughout the first 50 feet, and many plants were already dead in the first 10 feet. The response was at least as rapid and apparently as effective in preventing pollen shed as the water spray. Because of the possible advantage of more highly oil-soluble compounds in fog application, the ethyl ester of 2,4-D was prepared and tested on a small scale. Dimethyl ether aerosols gave responses on ragweed similar to 2,4-D.

Conclusion

Water sprays of 2,4-D at 1,000 ppm at sufficiently early stages of flower development were shown to be effective in preventing pollen shed, though further work may show that lower concentrations or rates of application would be sufficient. A preliminary trial with a fog machine showed excellent possibilities, and with further experiments to determine the best carrier, concentration, and technic of fog application it promises to be a more economical method than sprays. Apart from any differences in amounts of 2,4-D required in the two methods, the fog machine would have the advantages (1) of avoiding the large volumes of water necessary in spray methods, (2) of swifter application, and (3) of requiring considerably lower cost in equipment. This new technic of application, combined with relatively low cost, favorable selectivity of herbicidal action (*3*) and low toxicity (*5*), make 2,4-D a promising herbicide for ragweed control. It is hoped that these experiments will encourage others to test 2,4-D on a larger scale.

[2] Made available through the courtesy of the Todd Shipyards Corporation.

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Rapid Estimation of the Phytocidal Action of Chemicals[1]

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Recent reports on the herbicidal action of substituted phenoxy compounds (*1, 3, 5*)[2] have stimulated investigations of organic compounds which are essentially new to workers doing research on weed-control problems. The large number of organic compounds which might legitimately be selected for test as herbicides, together with the high cost and limited supplies of many of these chemicals, require that preliminary tests of their toxicity be simple, rapid, and economical. The utilization of *Lemna minor* L. (smaller duckweed) as a test plant fulfills most of these requirements.

The procedures here proposed should provide direct evidence of the effectiveness of chemicals for the destruction of aquatic plants—a matter of widespread interest and of economic importance. Tests with duckweed, however, will not necessarily indicate the magnitude of the toxic action of an unproved herbicide on a terrestrial plant. For investigators concerned with

[1] Work conducted for the purpose of improving methods for the chemical eradication of *Ribes* to control white-pine blister rust, *Cronartium ribicola* Fisher. Greenhouse and laboratory facilities, used by the Bureau of Entomology and Plant Quarantine at the University of California, Berkeley, are maintained in cooperation with the College of Agriculture through its Department of Forestry.

[2] The following features of 2,4-dichlorophenoxyacetic acid, a substituted phenoxy compound, differentiate it from compounds previously recognized as effective herbicides: (1) very low solubility in water, (2) telemorphic action, (3) effective killing action of small dosages, and (4) selectivity of toxic action. Data on the action of 2,4-dichlorophenoxyacetic acid as a differential herbicide are given by P. C. Marth and J. W. Mitchell (*Bot. Gaz.*, 1944, **106**, 224–232).

terrestrial plants, the proposed tests should provide useful data on the comparative phytocidal action of a group of new chemicals and, in particular, should indicate the relative toxicity of low concentrations of new and proved herbicides. In insecticidal as well as herbicidal investigations, there is considerable interest in recognition of the phytocidal action of low concentrations of chemicals. Data from tests with duckweed should facilitate evaluation of potential foliage damage by new chemicals, once preliminary standards have been established by which correlations can be made between reactions of duckweed and the particular foliage or plant under consideration. Tests with duckweed, or any other test plant in the laboratory or greenhouse, should be considered as preliminary to final evaluation of the herbicide under field conditions, and for the particular weed under investigation.

Aquatic plants such as *Nitella, Valonia, Chlorella,* and *Lemna* have been used extensively as test plants for many types of physiologic studies. *Nitella clavata* (Bertero) A. Br. has been used specifically to study the toxic action of the herbicide, sodium chlorate (*6*), and *Lemna minor* for investigations of the herbicidal properties of the oxyhalogens (*4*). More recently, growth stimulation by low concentrations of ammonium sulfamate (*2*) has been shown by the rate of increase in numbers of *Lemna minor.*

Lemna minor, a monocotyledon, is a chlorophyllose, floating aquatic plant which reproduces aggressively by vegetative means. The upper surface of its leaf-like stems, or fronds, is uniformly bright green. Large numbers of test plants can be maintained in small space in simple, inexpensive containers. Plants do well in dilute nutrient solution at a pH of about 5–6 or in tap water over a small amount of sandy soil, and can be grown readily at all times of the year. For ease of handling and convenience of observation, *Lemna minor* has recently been used in this laboratory in preference to other plants for rapid estimation of the toxic action of expensive chemicals. *Spirodela polyrhiza* was used for the same purpose, but the normal variegated color of its fronds interfered with observation of early symptoms of injury.

In preliminary tests of new herbicides made by the writer during an 18-month period, the rate and character of damage to *Lemna minor* were used as measures of toxicity. Four different, clearly detectable, and replicable reactions of *Lemna minor* were observed in the course of toxicity tests with herbicides in concentrations not immediately destructive to the tender plants. These reactions may be described as follows:

(a) Damage progresses steadily, as shown by chlorosis and discoloration of fronds. The end result is a generally uniform discoloration of the fronds. Plants are not split into components or frond combinations smaller than those originally present. The typical color of injured fronds is reddish brown to pale yellow or albino. There is no change in the total area of the fronds.

(b) Plants divide to form single or double fronds before discoloration becomes noticeable. Subsequent chlorosis takes place slowly, but uniformly, on all fronds. The end result is a generally uniform discoloration of fronds. Most or all of the plants are split into single fronds. The typical color of injured plants is a pale or yellowish green. There is no change in the total area of the fronds.

(c) Damage is slow and varies among the test plants. Single fronds break from the parent plant, and these separated fronds may be damaged while the fronds of the parent plant remain fairly green and normal in appearance. The end result is an uneven discoloration of fronds. There is no apparent change in total area of the fronds.

(d) Plants divide into single or double fronds without evidence of injury. Some stimulation of growth and regeneration is evident from the increase in the number and the total (estimated) area of the fronds. Fronds remain dark green in color and healthy until bacterial action, lack of nutrient, or protracted contact with the chemical solution causes injury.

In comparing the toxicity of an organic compound, such as 2,4-dichlorophenoxyacetic acid, with a series of its homologues or analogues, the following procedure is recommended: Prepare standard test solutions of the 2,4-D which provide a range of concentration from that which is rapidly toxic (1,000 ppm damages within a few hours) to that which is relatively nontoxic (10 ppm exerts no significant damage for several days). Prepare solutions of the new herbicides in concentration equivalent to the standard. Measure 50 ml. of the several test solutions into Petri dishes. Three replications are adequate for most purposes. Place the same number (10 or more) of duckweed plants in each test solution (including a control of tap water or a dilute nutrient solution of conventional composition), taking care to select vigorous, healthy plants of a uniformly green color. The number of fronds per plant need not be the same for all tests. For each culture, record the number of plants, the total number of fronds, and the time of immersion, so that comparisons between number of plants and fronds in the control and the several test solutions can be made at regular intervals. Unless the pH effect is the immediate object of the tests, the pH of the test solutions should be approximately the same, because excess acid or alkali exerts a definite toxic action on duckweed. The temperature of the solutions and the light intensity should also be generally comparable for all tests. Under these conditions the rate at which

damage occurs and the character of the damage, as previously described, will provide an estimate of toxicity of equivalent weights of the standard and the new herbicides.

Attention is called to the convenience and economy in the use of *Lemna minor* for estimating the phytocidal action of chemicals where a large number of tests are needed and where cost and availability of chemicals are important considerations. This plant may be useful as physiological test material in assaying the potency of commercial preparations of weed killers, particularly those containing organic poisons not easily determined by conventional methods of chemical analysis. Results of toxicity tests on duckweed should be directly applicable to practical problems in the control of aquatic plants.

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Tributyl Phosphate as a Solvent for Preparing Concentrated and Oil-miscible Solutions of 2,4-Dichlorophenoxyacetic Acid and Similar Substances [1]

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Concentrated solutions of many difficultly-soluble growth-regulating compounds for use in oil solutions may be prepared by the use of tributyl phosphate.

During the past few years much attention has been given to the use of 2,4-dichlorophenoxyacetic acid as a plant growth regulator and weed killer. For practical use in sprays, this compound, and others of a similar nature, must be used with a diluent or carrier. This acid is only slightly soluble in water, and attempts to dissolve it directly in inexpensive mineral oils, such as kerosene and fuel oil, have been unsuccessful. In an effort to find a suitable co-solvent of 2,4-dichlorophenoxyacetic acid for use in mineral oils, over 50 of the more common organic solvents were tested, and of these only tributyl phosphate proved satisfactory. The others were found to be unsuitable either by reason of insufficient solvent power, immiscibility with oil, or undesirable volatility. The co-solvent ability of tributyl phosphate in this combination is a critical property of this compound, since closely related substances such as triethyl phosphate and tricresyl phosphate are unsatisfactory.

At ordinary temperatures tributyl phosphate will dissolve up to about 36 per cent, by weight, of 2,4-dichlorophenoxyacetic acid. A range of from 5 to 36 per cent of the compound dissolved in tributyl phosphate was found convenient and useful for subsequent dilution with mineral oils. Best results have been obtained with solutions in which the ultimate concentration of 2,4-dichlorophenoxyacetic acid was from 0.5 to 5.0 per cent by weight after dilution of the tributyl phosphate solution with kerosene or low-grade fuel oil.

The solutions of 2,4-dichlorophenoxyacetic acid and tributyl phosphate are stable at ordinary temperatures, have no heat of solution when dissolved in mineral oils, and are miscible with them in all proportions. In addition, tributyl phosphate causes local burning of plant tissues at points of direct contact, which, for herbicidal purposes, may be desirable. There is evidence that greater inhibition, per unit weight of compound, is produced in some broad-leaved plants when 2,4-dichlorophenoxyacetic acid is applied in oil solutions containing tributyl phosphate than when the acid is applied in the form of aqueous solutions. It is not known whether the increased inhibitory effectiveness of such solutions is due to the contact injury produced by tributyl phosphate.

Tributyl phosphate also has been found to be capable of dissolving large amounts of 2,4,5-trichlorophenoxyacetic acid, para-chlorophenoxyacetic acid, 2-methyl-4-chlorophenoxyacetic acid and other substituted phenoxyacetic acids. In general, 2,4-dichlorophenoxyacetic acid can be replaced with equivalent amounts of one of the three compounds named above. This solvent likewise is useful in preparing concentrated solutions of mixtures of such compounds for use as such or in oil solutions.

[1] Studies conducted at Camp Detrick from January to September 1945, under the direction of Dr. A. G. Norman.

Treatment of Muck and Manure with 2,4-Dichlorophenoxyacetic Acid to Inhibit Germination of Weed Seeds [1]

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Herbicidal sprays containing 2,4-dichlorophenoxyacetic acid have been used to destroy noxious plants (*2, 3*). Aqueous sprays at 1,000 ppm are selective in

[1] Journal Article 787 (N.S.) from the Michigan Agricultural Experiment Station, accepted for publication December 1945.

ction, apparently not seriously affecting most grasses. Seeds of many plants, including grasses, can be destroyed by treatment with 2,4-dichlorophenoxyacetic acid. Concentrations as low as 1 ppm have a marked effect on germination and growth (*1*), and concentrations at 10 ppm will inhibit the germination of seeds of many plants. Although grass seeds are killed readily by 2,4-dichlorophenoxyacetic acid, high concentrations are required.

Muck soils and composted manure are frequently heavily infested with weed seeds. This suggests treatment of muck and manure to reduce the weed population. The importance of weed control is accentuated by the garden and truck crops commonly grown in muck and which require much hand weeding.

Muck soil in the vicinity of East Lansing, Michigan, was collected for treatment. The muck was placed in metal flats, and treatments were prepared at 1, 10, and 100 parts of 2,4-dichlorophenoxyacetic acid to 1,000 parts of muck. The 2,4-dichlorophenoxyacetic acid was applied to the muck in solution, a water-soluble preparation being used which contained 70 per cent of 2,4-dichlorophenoxyacetic acid obtained from the Dow Chemical Company. The concentrations were such as to give .01, .1, and 1 gram of 2,4-dichlorophenoxyacetic acid per square foot. After treatment, the muck flats were kept in a warm greenhouse at 60° to 80° F.

Two weeks after treatment, such weeds as lamb's-quarters (*Chenopodium album* L.), sow thistle (*Sonchus arvensis* L.), purslane (*Portulaca oleracea* L.), foxtail (*Setaria lutescens* Hub.), and redroot (*Amaranthus retroflexus* L.) began to appear in the untreated flats and to a much lesser degree in the flats containing 1 ppm of 2,4-dichlorophenoxyacetic acid. No weeds appeared in any of the flats treated at either 10 or 100 ppm of the chemical.

In order to test the residual effect in the soil, four weeks after treatment, bean and pea seeds were planted in the flats that had been treated at 10 and 100 ppm of 2,4-dichlorophenoxyacetic acid. The seeds germinated, and the plants grew normally.

In trials with 2,4-dichlorophenoxyacetic acid on manure, seeds of rape, rye grass, field pea, brome grass, meadow fescue, creeping bent grass, orchard grass, hairy vetch, and alsike clover were added to the manure in large numbers to insure their presence. The manure was then divided into three lots. One lot was treated at 10 ppm with 2,4-dichlorophenoxyacetic acid, a second was treated at 100 ppm and a third was left untreated as a check. The manure was then mixed with sand, the final mixture being about one part of manure to two parts of sand. The mixture was placed in metal flats and kept moist in a warm greenhouse. After three days, seeds in the control lot began to germinate, and after two weeks the surface of the mixture was covered with plant growth. The germination of seeds in the treated flats at 10 and 100 ppm was greatly inhibited, only a few of the grasses appearing in the 10 ppm flat.

Treatment with 2,4-dichlorophenoxyacetic acid is suggested as a method of controlling weed seed in manure and muck soils and where these materials are used in top dressings of lawns and golf courses. This treatment may also be of special value in conditioning nursery, tobacco, and other seed beds before planting.

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Herbicidal Action of 2,4-Dichlorophenoxyacetic Acid on the Water Hyacinth, *Eichornia crassipes*

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The water hyacinth, *Eichornia crassipes*, is a native of Japan and was carried about 70 years ago to South America, where it became widespread in fresh-water streams and lakes. At the International Cotton Exposition, held in New Orleans in 1884 (*1*), the Japanese government representatives gave away as souvenirs water hyacinths they had imported from Venezuela, where this pest had practically "taken over" the lower Orinoco. Very shortly thereafter the plant was introduced into Florida. Because it propagates prodigiously by both seeds and offshoots and matures two and sometimes three crops in a single season it presents a real problem in Florida and other subtropical regions, clogging the waterways, drainage ditches, and lakes.

Hildebrand and Palmiter (*3*) successfully employed the ammonium sulfamate herbicide for combating the *Prunus virginiana* wild host of the yellow-red virus disease of peach. Gowandloch (*1*) reviewed the various methods (chemical control, control by flame thrower, mechanical control, biological control) that have thus far been tried for water hyacinth control. He tested ammonium sulfamate and sulfamic acid for eradicating the water hyacinth and found that these killed only the plant parts above water.

Zimmerman and Hitchcock (*6*) developed some of the growth substances that may be toxic to plants in concentrations greater than that used to secure desirable responses such as rooting. Some of the more potent of these compounds are the substituted phenoxy

compounds, one of which, 2,4-dichlorophenoxyacetic acid (2,4-D), has received considerable attention as a herbicide.

Hamner and Tukey (*2*) reported on the herbicidal action of 2,4-D on bindweed, *Convolvulus arvensis*, and on a number of other plant weeds. They also found the related compound, 2,4,5-trichlorophenoxyacetic acid, showing promise as a herbicide. In this and in subsequent study by others (e.g. *4, 5*), 2,4-D worked best on broad-leaved plants.

In April 1945 the writer first tested 2,4-D (1:1430) for eradicating the water hyacinth in a flowing stream of water. In preliminary trials promising results were obtained by spraying with a knapsack sprayer from the shore. Three areas, each involving several hundred plants, were treated. The amount of material employed was about one gallon per 100 square feet for plants about 15 inches tall. One week after application the upper parts were epinastic and discolored. By the end of two weeks both the above- and below-water parts were nearly all dead, the stems separating from the roots, and the dead parts disappearing in the stream either by sinking or floating away within three weeks.

In the second experiment several irregular patches of water hyacinth plants, which were partially clogging the creek, were sprayed from a boat with 2,4-D (1:1140). As in the previous experiment, the above-water parts were well moistened with a coarse spray until dripping started. Again the sprayed plants died and disappeared in the stream in about three weeks.

A third experiment, a repetition of the second in most details, gave similar results. The 2,4-D chemical plus Carbowax 1500, according to the formula of Hamner and Tukey (*2*), was employed. This preparation seemed to give an improved surface coating on the hyacinth foliage. However, practically 100 per cent kill was obtained, and the sprayed specimens disappeared in the stream in the treated areas, whereas the untreated check plants remained normal and in place. These studies seemed to have demonstrated the feasibility of removing the water hyacinth from streams.

Small fingerling fish and other water fauna were abundantly present among the water hyacinth growths before, during, and after spraying with 2,4-D. No adverse effects to the water fauna were observed up through the time of disappearance of the plants at the end of the experiments. Since 2,4-D is a growth substance for plants which operates on the "hormone" principle, injurious effects to water fauna were not anticipated or encountered from its use.

Starting early in October a second series of experiments was conducted for eradicating water hyacinths growing in relatively quiet water, in a rectangular, excavated pond with water ranging from 4 to 8 feet deep. The water hyacinths invaded this pond through a small drainage ditch and covered the surface in a few months time. The growth was vigorous, dense, 16 to 24 inches tall, and in bloom at the start of the experiment. One-gallon quantities of 2,4-D spray ranging in concentration from 1:800 to 1:1700, when applied in 100-square-feet plots and replicated three times, all gave practically complete control. The use of Carbowax as a wetting agent did not seem to improve the herbicidal action of 2,4-D. When the spray concentration (1:1000) was held constant, one gallon gave complete control for areas ranging from 100 to 150 square feet. In another experiment where both the concentrations and areas treated were varied, one gallon of 2,4-D (1:1700), when applied to plots 150 square feet in area, failed to give complete control, although over 90 per cent kill was obtained. In one experiment when rain fell before the 2,4-D spray had time to dry or be absorbed, the herbicidal action was largely lost.

The first conspicuous symptom of herbicidal action, consisting of an abrupt epinasty or downward bending of the upper part of the leaf petiole, appeared about two days after spray application. Subsequently discoloration and death occurred in about three weeks. Although chlorotic and decomposing, the last part to remain floating was the buoyant, enlarged, lower portion of the petiole. By the time the plants were dead in the treated plots the surrounding growth was moving in to occupy the vacated space. Therefore, to control the water hyacinth all the plants in a given area, rather than small portions of an area, must be sprayed.

In order to study the more intimate details of the effects of 2,4-D, another series of experiments was conducted during the winter, employing open, 50-gallon drums to which 12 to 20 plants were transferred. The first experiment consisted in spraying the plants in three drums with 2,4-D (1:1000) at three successive weekly intervals starting the last week in November. The plants in four drums were held as checks. The sequence in symptom development of previous experiments was repeated and confirmed, but the rate or speed of herbicidal action was slowed by over two weeks. Here, however, all plants died, decomposed, or settled to the bottom. Various forms of water fauna, including mosquitoes, were present in abundance, as was duckweed.

The second and final drum experiment was started in February and concluded in March. Around 25 small hyacinth plants about 4 inches tall were placed in each drum. Five different sources of 2,4-D, diluted 1:1000 and including one of the acid form, two salts of the acid, and two esters of the acid, were each ap-

plied to the plants in two drums, leaving three checks. Because of the smaller size of the plants, the rate of herbicidal action was increased over that of previous experiments with larger plants. The roots did not die and decompose as rapidly as the stem portion, yet they appeared to have lost the power to produce offshoots. As the result of this study, the form of the 2,4-D preparation used seemed to make no difference in herbicidal action provided the leaves were well moistened and the 2,4-D spray allowed to dry and penetrate into the leaves.

The possibility that important waterways might be cleared of the water hyacinth by means of 2,4-D invites trial on a larger scale. The "Water Buffalo" amphibian tractor might be useful in this connection.

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Science Legislation

Selective Service and Student Personnel

Howard A. Meyerhoff

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The recruitment of scientific and engineering students has just been dealt another blow by Selective Service and the Army—and perhaps by Congress, which may approve the extension of Selective Service for another nine months before this issue of *Science* reaches its readers. The bill extending Selective Service, by providing for the deferment of farm hands, will lay an especially heavy hand upon the students in our colleges and universities. If it passes in its present form, any hope that engineers and scientists may have had to recoup some of the losses incurred through the draft during the war will be gone for another year.

As every engineer and scientist knows, considerably more than 100,000 potential scientists were sacrificed during the war years, thanks to a military policy which made no provision whatever for the replacement of expendable scientific personnel. Neither our allies nor our enemies in the late war were as short-sighted as this, for most of them provided deferment for students who were specializing in scientific and engineering studies, and some of them encouraged new students of draft age to enter these professions. In dismal contrast to other nations, we not only drafted our prospective scientists and engineers, but also assigned them to military duties quite unrelated to the training which most of them had acquired. The Navy seems to have taken into account the special ability of students in so far as their training might prove useful, but the Army quite commonly showed a complete disregard of any background which even advanced students in specialized fields had acquired. This statement can be supported by the citation of any number of examples, but a quotation from one of several letters from young scientists will demonstrate the flagrant waste of scientific personnel, for which the Army must assume responsibility:

> So, with ten years of scientific training in biology, I was turned back to menial work (in an army hospital laboratory), most of which could be performed by a janitor. What with floor-mopping, latrine-cleaning (barracks and laboratory), window-cleaning, and scouring of glassware, three-fourths of one's time was spent on the sort of tasks for which any rookie chosen at random could be trained in one week.

There is in Army and Selective Service circles the bland assumption that returning veterans are filling in the gaps created by war, and letters from General Hershey addressed to the office of the Permanent Secretary reveal the lack of a factual basis for such an assumption. On 20 February he wrote:

> I am fully aware of the importance of the student group in which your Association has a vital interest. The technical, scientific and professional fields should be given due credit for their important contributions in the winning of the war and for the part they will play in the future.
>
> Veterans and other students are now entering college and university in very large numbers. They are studying at all levels ranging from the freshman class through graduate work. There is reason to believe that the rapid upward trend in enrollment will continue for some time. Engineering, scientific and professional study occupy a

prominent place in a very large number of colleges and universities, and these fields of study are now attracting many veterans.

Large numbers of colleges of all types, located in various sections of the country, report they already have capacity enrollments and that their ability to take care of additional students is limited by housing, staff, laboratory and classroom shortages. Many of these institutions are deeply concerned about the students who cannot be admitted because of the limited facilities. Temporary expedients are under wide discussion and some emergency arrangements have already been developed.

The situation is so critical that many special conferences are being called to consider the problem. State officials as well as colleges and university associations are urging that immediate steps be taken to provide educational opportunities for veterans and others now desiring admission.

In view of the present conditions, the problem seems to be that of accommodating the available and qualified students. If those entering are not pursuing the proper fields of study or courses, it would appear to be a matter of channelling them into the critical fields of study and where the best vocational opportunities exist.

The facts of the situation hardly warrant General Hershey's optimistic statement that "these (scientific) fields of study are now attracting many veterans." The statistics of enrollment for 110 enginering schools and colleges as of December, shown in Table 1, are eloquent.

TABLE 1

	Freshmen		Sophomores		Juniors		Seniors	
	N	%	N	%	N	%	N	%
Prewar norm	34	100	24	100	20	100	15	100
December 1945	32	94	12	50	7	35	4	27
Nonveteran	23	67	8	33	5	25	3	20
Veteran	9	27	4	17	2	10	1	7

Totals for all four years of engineering training may be summarized as shown in Table 2.

As of April 1946, the ratio of veterans to nonveterans has changed, but not for the reason that General Hershey thinks. Deferment was granted to civilian

TABLE 2

	N	%	Veteran %
Prewar norm	93	100	...
December 1945	55	59	100
Nonveteran	39	42	71
Veteran	16	17	29

students until the end of the fall semester and was then withdrawn. The net result was to increase the proportion of veterans but to reduce the total of engineering students.

Probably the most interesting statement in the letter quoted is the concluding sentence. One wonders how veterans recently discharged from military discipline can be "channeled" into the critical fields of study, or why nonveterans who have chosen to enter these same "critical fields" should be "channeled" out, especially when they are far more critical to national security than the recruitment of approximately 20,000 men for military service.

Surely, it is not too much to ask military authorities to keep a vital long-range need in mind while solving two very temporary, if acute, problems. Or, if military authorities are incapable of dealing with so many problems simultaneously, it is not unreasonable to demand that the solution be placed in the hands of some authority able to effect it. Competence in engineering and science requires years of study and more years of experience. The war has cut our roster of scientific and technological manpower at least 12 per cent, and it is now proposed, not merely to prevent recovery, but also to cut the percentage farther.

As this article goes to press, the House is debating the bill. Representative May, chairman of the House Military Affairs Committee, introduced an amendment in Committee providing some protection for students, but it was voted down. Representatives Clason and Martin (of Iowa) introduced and supported a similar amendment on the floor of the House, but its fate is at the moment unknown. The chances of defeat are better than even.

Do engineers and scientists propose to sit by and take another beating?

U. S. News and Notes

Henry K. Townes, *Kenneth L. Sherman*, and *Robert Simha* were honored by the Washington Academy of Sciences at a meeting on 21 March 1946 for their respective contributions to the biological, engineering, and physical sciences.

The citations read: Henry K. Townes, Bureau of Entomology and Plant Quarantine, Beltsville, Maryland, in recognition of his distinguished service in the morphology and taxonomy of the insect superfamily Ichneumonoidea; Kenneth L. Sherman, Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D. C., in recognition of his distinguished service in advancing the technique of atmospheric electric measurements; Robert Simha,

National Bureau of Standards, Washington, D. C., in recognition of his distinguished service in the physical chemistry of high polymers and the theory of their physical properties.

Dr. David E. Green, research associate in the Columbia University College of Physicians and Surgeons, has won the first Paul-Lewis Laboratories Award in Enzyme Chemistry, it is announced by the American Chemical Society, which administers the award. Sponsored by the Paul-Lewis Laboratories, Inc., of Milwaukee, Wisconsin, the annual award of $1,000 and a bronze medal was established this year to stimulate fundamental research by young graduates of American colleges or universities in the field of enzymes.

Dr. Reinhold Rudenberg, inventor of the electron microscope, received the Stevens Honor Award for notable achievement in the field of Electron Optics upon the occasion of the seventy-sixth Anniversay Annual Dinner of the Alumni of Stevens Institute of Technology. Dr. Rudenberg, now Gordon McKay professor of electrical engineering at Harvard University Graduate School, is also consultant to the Farrand Optical Company of New York, where he is developing an electron microscope of advanced design.

Announcements

The Texas Academy of Science held its 1945 annual meeting on 8, 9, and 10 November at Baylor University, Waco, Texas. A total of 96 papers were presented. In the report of the president, Walter P. Taylor, the course was charted which the organization must follow if it is to assume its rightful responsibility in the advancement of scientific knowledge in Texas. The president as well as the vice-presidents in the several sections emphasized the desire to encourage the growth of the collegiate section in order to bridge the serious gap in the depleted ranks of the young scientists occasioned by the war. Among other things, it was urged that grants-in-aid and fellowships be established and that greater participation in the program and official capacities be permitted to encourage the younger members.

The following were elected Honorary Life Fellows: W. J. Battle, University of Texas; F. A. Burt, A. and M. College; and Wallace Pratt, of the Standard Oil Company.

The first issue of Science Illustrated, published by the McGraw-Hill Publishing Company, was released on 1 April. This is a new general magazine from the science point of view, with a printing order of 500,000 copies, a record for new publications.

The editorial director is Dr. Gerald Wendt, former science editor of *Time.* The medical and biological editor is Dr. Barry Commoner, formerly instructor of biology at Queens College, New York, and until recently a lieutenant in the USNR, engaged in research on aviation medicine.

The two new elements, 95 and 96, were given names by Glenn T. Seaborg at the meeting of the Physical and Inorganic Division of the American Chemical Society meeting at Atlantic City on 10 April. He recommended that 95 be called "americium" with the symbol, Am, after the Americas, and that 96 be called "curium" with the symbol, Cm, after the Curies. Dr. Seaborg also recommended that the soft "c" be used in the pronunciation of americium, but some of his hearers thought that it would not be long until the second "i" will be dropped and the pronunciation changed, in the United States at least, following the history of aluminium.

Several scientists have expressed the view within the past week that a plan for international control of atomic energy which hinged on a "denaturing" process (*Science,* 1946, **103**, 428, 451) would not by its very nature be a successful one, and that the ultimate solution lay in the development of a strong organization for the control of nuclear energy.

The American Society of Agronomy and *Soil Science Society of America* held their annual meeting at the Deshler-Wallick Hotel, Columbus, Ohio, on 26 February to 1 March 1946 with over 635 registering. The first day was devoted to a report of the National Joint Committees on Fertilizer Application and Nitrogen Utilization. Highlights of the meetings were: (1) The general meeting at which "Opportunities and Responsibilities of Agronomists" were discussed. Dr. P. V. Cardon, of the Agricultural Research Administration, spoke on the "International Aspects" of the subject and Dr. Richard Bradfield, of Cornell University, on "Domestic Aspects"; (2) the annual banquet, at which Dr. F. W. Parker, president of the American Society of Agronomy, gave the presidential address on "The Nitrogen Problem in Soil Management," and at which members serving their country on special assignments during the war period were recognized. The remainder of the four-day meeting was taken up with general and special sessions on various phases of soils and crops.

The seventeenth annual Stuart McGuire Lecture Series given by Dr. Elmer L. Sevringhaus, professor of medicine at the University of Wisconsin Medical School, was combined with the spring postgraduate clinic at the Medical College of Virginia this year.

Meetings

The American Mathematical Society will hold its 415th and 416th meetings on 26–27 April at Columbia University, New York City, and the Museum of Sci-

ence and Industry, Chicago, respectively. The 417th meeting will be held on 27 April at the University of California, Berkeley.

The Twentieth Colloid Symposium will be held at the University of Wisconsin, Madison, on 28–29 May 1946. As on the occasion of the First Colloid Symposium, which also met in Madison, Prof. The Svedberg, of the University of Upsala, Sweden, is to be the guest of honor.

One day of the meeting will be devoted to the topic: "The Physical Chemistry of High Molecular Weight Materials." Papers on this topic will be given at two concurrent sessions, one concerned with the proteins and the second with organic high polymers. Dr. Svedberg is to preside at the session on proteins, and Dr. Paul Flory, of the Research Department of the Goodyear Rubber Company, is in charge of the arrangements for the high polymer session.

On the second day a program of general papers has been planned by Dr. H. B. Weiser, with the cooperation of members of the Colloid Symposium Committee.

Arrangements have been made for housing at one of the University dormitories, and meals can be taken at the Commons. Those who expect to attend the Symposium should notify Prof. C. H. Sorum, Department of Chemistry, Madison, Wisconsin, before 20 May to insure accommodations. Rooms will be available for the nights of 27, 28, and 29 May.

Elections

The American Society of Agronomy has elected the following officers for 1946: H. D. Hughes, Iowa State College, president; W. H. Pierre, Iowa State College, vice-president; J. D. Luckett, New York Agricultural Experiment Station, editor; G. G. Pohlman, West Virginia University, secretary-treasurer; E. A. Hollowell, Bureau of Plant Industry, Soils and Agricultural Engineering, chairman of Crops Division; and C. E. Marshall, University of Missouri, chairman of Soils Division.

The Soil Science Society of America reports election of the following officers for 1946: C. E. Marshall, University of Missouri, president; F. L. Duley, University of Nebraska, vice-president.

Recent Deaths

Dr. Harold E. Robertson, 67, senior consultant in the Mayo Clinic section on pathological anatomy and former head of that section, died on 8 March.

Dr. William Morton Barrows, 62, professor of zoology and entomology at Ohio State University, died on 24 February. He had been associated with the University since 1909.

Dr. Bernice L. Maclean, 42, zoologist and former chairman of the Department of Biological Sciences at Hunter College, died in New York City on 8 March.

Mary B. Eyre, 70, professor emeritus of psychology at Scripps College and professor of psychology at the Claremont Graduate School, died on 25 January following injuries sustained in a traffic accident.

William Crowell Bray, 66, professor of chemistry at the University of California, died on 24 February following an illness of several months.

Carl L. A. Schmidt, 60, professor of biochemistry and chairman of the Division in the University of California Medical School for 23 years, died after a long illness on 23 February.

International News and Notes

L. H. Bailey and *A. J. Eames,* of Cornell University, and *E. D. Merrill* and *Frans Verdoorn,* of the Arnold Arboretum of Harvard University, have been elected honorary foreign members of the Botanical Society of Edinburgh.

Dr. Herbert Spencer Gasser, winner of the 1944 Nobel Prize in medicine and physiology, and since 1935 head of the Rockefeller Institute in New York, has been made a member of the Swedish Royal Academy of Science.

Dr. Arthur Stoll of Basle, Switzerland, director of the Sandoz Research Laboratories, is the recipient of an honorary doctorate, conferred by the Sorbonne for his fundamental contributions to the chemistry of the glycosides of digitalis and squill and for his work in the field of the alkaloids of ergot.

Robert S. Tipson, senior fellow in Pure Research at Mellon Institute, was awarded the D.Sc. degree by the University of Birmingham, England. The same degree was also awarded to another scientist, Owen W. Ellis, of the Ontario Research Foundation, Toronto, formerly an industrial fellow of Mellon Institute.

Dr. Cornelio L. Sagui (18 Rue Luchet, Avignon, France) writes to Dr. Charles H. Behre, Jr., pro-

essor of geology at Columbia University, that geology in France is once more beginning to resume its normal peacetime role, one of its most prominent functions being in the field of reconstruction. The Association International pour l'Etude Scientifique des Pays Mediterraneans is in process of being organized, and some of its problems will lie in the fields of general and economic geology. Dr. Sagui is studying and publishing in several fields. One of his most recent investigations concerns the pressure of magma in intrusive bodies. Fernand Blondel, well known in this country as a Fellow of the Geological Society of America and as a member of the Society of Economic Geologists, has just returned to Paris (24 Rue Vineuse) after prolonged service in French North Africa. Dr. Jean F. Orcel (61 Rue de Buffon) has resumed his post of curator in mineralogy at the Museum National d'Histoire Naturelle. Dr. Gaston Betier is back at his post in Algeria. Mr. J. Durand, still with the Bureau des Mines in Toulouse, has been stationed at intervals at Saint Gaudens, where he has been directing special research on petroleum for the Government.

In Belgium, Prof. Ivan De Magnee writes through Dr. Sagui, theoretical and applied geology are being pursued with renewed vigor. Prof. De Magnee at the University of Brussels (15 Rue des Nations, Bruxelles) has founded a laboratory for geophysical research, in part directed toward new prospecting in the Congo. Prof. Paul F. Fourmarier, after imprisonment by the Gestapo, is once more at his old post at the Institut de Geologie, University of Liège, as is Prof. Victor Brien.

Dr. M. S. Krishnan, superintending geologist of the Geological Survey of India, comments on the difficulties of the war years, among which was a serious paper shortage which cut to about a third the volume of scientific and technical publications. He adds, however, that there are signs that publication will be resumed shortly on the old scale.

Dr. Wallace P. Cohoe, a consulting chemist, 120 East 41st Street, New York, will receive the Messel Medal of the Society of Chemical Industry at the annual meeting of the Society in England on 12 July 1946. In the Messel Lecture he will discuss "The Importance of Science in Anglo-American Relationships."

The Messel Medal is awarded every other year for meritorious distinction in science or in the literature of chemistry or for meritorious service to chemical industry. Two other Americans have received the Messel Medal, Prof. R. A. Millikan in 1928 and Dr. Leo H. Baekeland in 1938. The other 10 recipients, all English, were: Prof. H. E. Armstrong, Rt. Hon. Viscount Leverhulme, Rt. Hon. Earl of Balfour, Rt. Hon. Lord Brotherton of Wakefield, Sir William J. Pope, Sir Harry McGowan (now the Rt. Hon. Lord McGowan), Sir Robert Mond, Rt. Hon. Viscount Samuel, Sir John Russell, and Prof. A. V. Hill.

Dr. Pierre Bonnet, of the Laboratoire de Zoologie, Université de Toulouse, France, writes that he is well in spite of having had some narrow escapes during the bombings. Working under difficulties, he has continued to amass material for his three-volume *Bibliographia Araneorum,* the first volume of which appeared off the press last September. It is a volume of 830 pages and contains 106 portraits of past and present workers in the field of araneology. He also writes that Dr. J. Denis is still at Donchy, and Profs. L. Fage, L. Berland, and J. Millot are still in Paris. All are anxious to receive the publications of their American colleagues.—*B. J. Kaston* (Syracuse University).

Prof. Yun-Pu Liu, organic chemist, who was in the United States as a research fellow of the China Foundation and of the Rockefeller Foundation from 1931 to 1934, receiving his Ph.D. at the California Institute of Technology, writes that he is now teaching in the National University of Chungking. He states that the Chinese Ministry of Education has recently announced that university professors with seven years of service may apply to go to the United States or England on an exchange basis, provided they can secure some kind of appointment, such as research work or teaching jobs by their own arrangement. The Ministry is to pay only the traveling expenses of such individuals. Prof. Liu is among those eager to obtain a suitable appointment in the United States.—*Maurice L. Huggins* (Eastman Kodak Company).

Dr. Luigi Provasoli, of Italy, whose work in the nutrition of green and colorless flagellates is well-known in the field of comparative physiology, writes that he has been isolated from American research literature for the past six years, and that it is still very difficult to secure scientific books or journals in Italy. He would appreciate it very much if the authors of papers dealing with the nutrition of Protozoa could send him their reprints. His address is: Universitá, Camerino, Italy.

Dr. Provasoli feels that he and his family came through the war in a relatively fortunate manner. He experienced only a brief period in a concentration camp. He has not yet been able to return to his prewar position at Milan because conditions in that city are hardly conducive to scholarly work: electricity is available about every other day, gas for two hours a day, and wood is so scarce and expensive that heat is almost unknown.

As Dr. Provasoli says, let us "hope that the few men of good will will succeed to make fully understood that our safety is only in a united world policy and in the strong and truthful building of an organization governing the entire world.—*William Trager* (Rockefeller Institute, Princeton, New Jersey).

Prof. C. Bonne, head of the Department of Pathology in the Government Medical School in Batavia, has written to Dr. Morris E. Dailey, University of California Hospital, San Francisco. Portions of his letter, dated 12 February 1946, follow:

The European staff members of the School have all been interned by the Japanese, most of them, including myself, for three and one-half years. I am recuperating now in Australia with a few of my colleagues; others have gone to Holland and others are still in Java. Many of us have been severely ill, but there were no deaths amongst us. In January this year the Medical School was still in the hands of the Indonesians. School and hospital did not suffer much damage mainly due to the wise cares of our Indonesian assistants. I hope to be able to resume my work in my old position when a settlement between the Dutch and Indonesians is reached.

Prof. Bonne's present address is: c/o Mrs. Bonne, Main Avenue, Coorparoo, Brisbane, Queensland, Australia.

An international conference, called by the executive committee of the International Astronomical Union met in Copenhagen on 7–11 March. The American delegation—Harlow Shapley, director of the Harvard University Observatory; Otto Struve, director of the Yerkes Observatory of the University of Chicago and of the McDonald Observatory of the University of Texas; and Joel Stebbins, director of the Washburn Observatory of the University of Wisconsin and a research associate of the Mount Wilson Observatory at Pasadena, California—left the United States on 2 March, flying from La Guardia Field.

The more precise determination of star positions was one of the matters considered at Copenhagen. This conference is expected to redistribute international services that were assigned to Germany, wholly in German hands, for the interwar period. It is likely that Russia will take over one or two of these service bureaus, which deal with planetary motions, with variable stars, and with the international time services.

In the Laboratory

Inhibition of Fungus Respiration: a Metabolic Bio-assay Method [1]

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In the search for chemical substances active against disease-producing organisms, one is frequently confronted with difficulties in establishing criteria for activity. In a stimulating series of papers on the principles and practices of laboratory testing of fungicides, McCallan and Wilcoxon (*7*) bring out the close relationship of bio-assay methods in general and speak of two categories of assays: (1) that in which the effect of a toxic agent on an organism is *measured* quantitatively, and (2) that in which some phenomenon in the form of a "response" (an event either does or does not happen) of an organism is *observed.* Nearly all bio-assay methods for fungicides and bacteriocides in current use are examples of Type 2. Among these may be mentioned the various spore-germination tests and the U. S. Food and Drug Administration methods (*11*) for testing antiseptics, wherein the highest dilution of a chemical completely inhibiting growth is observed. The agar cup-plate methods, utilized in penicillin assay, are further examples, since one determines essentially a zone of concentration which inhibits growth.

While observations of certain responses of an organism, *i.e.* the germination or nongermination of spores, growth or absence of growth, have provided much valuable information on antiseptics, disinfectants, and substances with chemotherapeutic activity, need is felt at times for methods that will reveal the extent to which a foreign agent affects a healthy, growing culture. This is particularly true with the pathogenic fungi. We know of chemicals that keep spores from germinating or prevent fungus mycelia from entering a zone of given concentration of chemical on an agar plate. However, in spite of several studies on the correlation between laboratory and clinical findings, our information on what (to say nothing of the mechanism whereby) the chemicals do to "adult" fungi is extremely scanty. In the treat-

[1] The author appreciates the interest and aid of Dr. J. G. Hopkins, Lt.Col. Laurence Irving, and Lt.Col. J. R. Scholtz in the work reported here and to be described.

ent of fungus infections we are primarily concerned ith the removal of an established parasite and secdarily with prevention of reinfection. Information om "response" tests is directly applicable to conderations of reinfection but only indirectly to an isting infection. It is clear that all fungus infecions are not acquired via the fungus spore; indeed, he mode of transmission of fungus infections is far rom being clearly explained with some evidence inriminating mycelia contained in skin debris as the nfecting agent. Though fungus spores are notoriusly resistant, it does not follow that treatment which prevents their germination will also be lethal o mycelial fragments (capable of growth) contained n skin debris in which the protective action of tissue and other factors are possibly operative.

The present unsatisfactory state of treatment for fungus infections may, in part, reflect our lack of satisfactory methods for testing *in vitro* the effects of chemicals on the fungus in a state of organization comparable to that *in situ*.

In view of the foregoing, convenient methods furnishing quantitative data on the immediate effect of a chemical on a mycelial organization of a fungus would be welcome. It is shown that such may be found in quantitative measurements of oxygen consumption by fungus cultures or samples therefrom; the methods may be extended to fungus mycelia contained in skin debris.

Cultures of pathogenic fungi freshly isolated from foot lesions were identified following Emmons (*5*), and Conant, *et al.* (*2*). These cultures and cultures of fungi received from Duke University Medical School[2] were inoculated onto plates of Sabouraud's dextrose agar and Difco-cornmeal agar. Transfers were also inoculated into a liquid medium. The following organisms were used: ***Trichophyton gypseum***, *T. rubrum*, and ***Epidermophyton floccosum***.

The filamentous fungi grow in the form of a mat on the surface of agar media and, unless disturbed, grow similarly on the surface of liquid media. Attempts to harvest such growth and to homogenize it in some way (such as by sucking in and expelling from a syringe) for use as a suspension have been reported occasionally, but such techniques defeat the purpose; the mycelial components are usually ruptured and one most often obtains merely a spore suspension. Using a sterile cork borer of 15-mm. diameter, cylinders were cut from agar-plate cultures, two or four weeks old. The discs were placed in a respirometer in 1 cc. of liquid. It made no difference whether the disc was placed so that the mycelial side or the agar side was face down in the liquid. After the experimental period in the respirometer the disc was dropped into boiling water to remove the agar, lifted from the water after 1 minute, drained, and placed on a previously weighed, clean, dry cover slip. Dry-weight determinations were made by heating the fungus and cover slip for 12 hours at 100° C. Loss of weight by the fungus mycelium during the brief hot-water extraction was found to be negligible. After

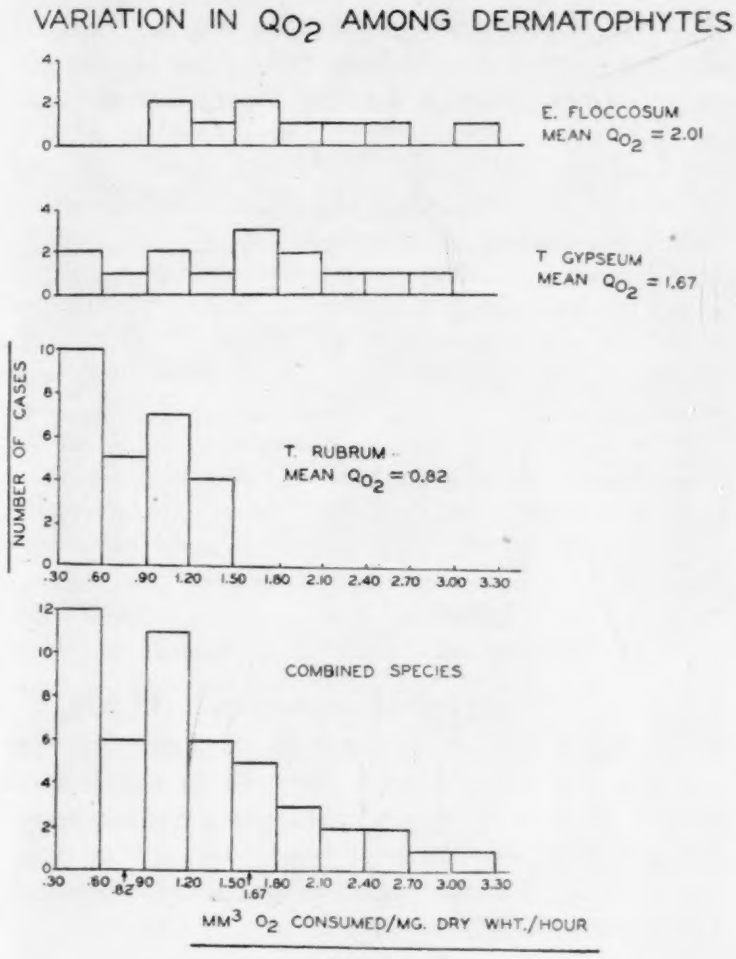

FIG. 1

the drying and weighing the cover slip and fungus were mounted, in lactophenol cotton blue, on a slide to give a permanent record of the organism used in each experiment. With this record, contamination, if such occurred, would be easily discovered. Samples of fungus from liquid cultures were obtained simply by use of a wire, flattened at the end to a sharp cutting edge capable of being flamed. Pieces of mycelium were lifted out, drained, rinsed in sterile distilled water, and placed in 1 cc. of liquid in the respirometer vessel.

A volumetric microrespirometer described by Scholander and by Scholander and Edwards (*9*) was used in the present work.[3] This instrument, discussed by Glick (*6*), employs an ordinary micrometer to displace mercury from the reservoir of a Rehberg-type microburette and has a sensitivity of 1/3 mm.³/hour. An

[2] The kindness of Dr. N. F. Conant in supplying cultures of organisms is appreciated.

[3] It is a pleasure to acknowledge the helpful discussion with Major P. F. Scholander and Lt. G. A. Edwards during the course of this work.

important feature of the instrument is that the pressure of oxygen in the vessel is maintained constant during long experiments.

The influence of several classes of chemical substances under different environmental conditions on the oxygen consumption by species of dermatophytes will be reported elsewhere (*8*); a few examples will suffice here. Variation in the Q_{O_2} ($mm.^3$ O_2 consumed/mg. dry weight/hour) among isolates of the three species examined is shown in Fig. 1. Four of the values given for *Trichophyton gypseum* are for oxygen consumption in distilled water; for the other

TABLE 1

EFFECT OF INORGANIC SALTS ON OXYGEN CONSUMPTION BY DERMATOPHYTES

Compound	Concentration	Organism	Change from Q_{O_2} in M/15 KH_2PO_4 buffer at pH 4.6
			%
$ZnCl_2$	$10^{-2}M$	*E. floccosum*	− 93
$ZnCl_2$	$10^{-3}M$	*T. rubrum*	− 32
$Zn(NO_3)_2$	$10^{-3}M$	"	− 22
$ZnCl_2$	$10^{-4}M$	*T. gypseum*	− 13
$CdCl_2$	$10^{-2}M$	*T. rubrum*	− 22
$CdSO_4$	$10^{-2}M$	"	+ 37
$AgNO_3$	$10^{-2}M$	"	− 100
$AgNO_3$	$10^{-4}M$	"	− 43
$HgCl_2$	$10^{-2}M$	"	− 74
$HgCl_2$	$10^{-3}M$	"	− 28

two species all values were obtained in M/15 KH_2PO_4 buffer at pH 4.6; no substrate or other chemical was added in any case. After a preliminary equilibration period, the rate of oxygen consumption for all organisms examined was linear for several hours. The mean Q_{O_2} of 0.82 (26 cases) for *T. rubrum* sets it somewhat apart from the other species examined.

Certain inorganic water-soluble salts were examined for effect on fungus respiration. As will be seen in Table 1, mercury, silver, and zinc in similar concentrations depressed respiration to a comparable extent; cadmium compounds had little effect. Addition of 1/100 molar sodium propionate to *E. floccosum* in M/15 KH_2PO_4 buffer resulted in three experiments in inhibitions of 13, 27, and 35 per cent, respectively, of the basal Q_{O_2} in plain buffer. Removal of the propionate by washing with buffer and return of the fungus to buffer was followed in each of the three cases by a rise in the Q_{O_2} to the initial basal rate in plain buffer. Exposure of *E. floccosum* to 1/100 molar zinc chloride for three hours was not followed by recovery in the Q_{O_2} when the salt was removed; the fungus was incapable of further growth when transferred to an agar medium after such treatment.

Clinical trials with dilute (1 per cent) solutions of zinc chloride showed it to be of promise in the treatment of tinea cruris and tinea glabrosa. A report on this work is in preparation (*3*).

The use of respiration studies in connection wi[th] problems of skin infection has been advised befor[e] Bronfenbrenner, Hershey, and Doubly (*1*) and El[y] (*4*) advocated use of manometric methods for evalua[tion] of germicides, but few publications have appeare[d] in this vein. It is believed from the present stud[y] that the uncovering and evaluation of substances fo[r] chemotherapeutic use in fungus infections by deter[mination] of their effect on fungus respiration is [a] practical and desirable procedure. Chemical sub[stances] proposed as fungicidal or fungistatic agent[s] can easily be subjected to critical test through mea[surement] of inhibitory action on fungus respiration.

Though the metabolism of the pathogenic fungi is practically unknown, it is realized that inhibition of oxygen consumption may be an insignificant matter with some species if the organism in question happens to employ hydrogen acceptors other than oxygen for the bulk of its metabolism. Sevag, Richardson, and Henry (*10*) have stated this problem very clearly in their studies on the mode of action of sulfonamides on the respiration of bacteria. With the species herein discussed, oxygen consumption is apparently a critical index of metabolism and inhibition of respiration a valuable *in vitro* criterion of the effect of chemotherapeutic agents on these organisms.

The application of the method presented is not limited to the dermatophytes. One can apply it to the fungi causing deterioration of textiles and other equipment in wet tropical climates. A small sample of cloth infected with an assortment of organisms may be placed in a respirometer and the oxygen consumption of this *microcosm* measured. Various chemicals may then be added and their comparative inhibitory effect on respiration noted. This procedure would enable one to determine the effect of treatment on a mixed population in which synergistic phenomena are doubtless in operation.

In actuality, any situation in which mycelial growth of fungi needs to be controlled could profit from the application of metabolic criteria to the activity of a fungicidal or fungistatic agent.

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Letters to the Editor

Effects of New Herbicides on Fish

During the course of some experiments to determine the effects of certain of the new herbicides on fish, we set up some tests, largely out of curiosity, using the new rodenticide 1080. In view of the extreme toxicity of this substance, as reported by E. R. Kalmbach (*Science*, 1945, 102, 232), we were certainly surprised to find that fingerling bream and bass would survive in concentrations of 1080 as great as 370 ppm for an indefinite period and with no apparent discomfort.

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Some Reflections on the Cause of Heat and Cold

Not many Americans know of M. V. Lomonósov, a noted Russian scientist, and very few are aware of the scope of his research. The writer of this article wishes to pay tribute to this great early Russian physicist, one of the first academicians of the Russian Academy of Sciences, for his research in the theory of heat.

M. V. Lomonósov's name has never been mentioned in the West-European and American scientific literature in connection with the development of our concept of heat, although he, as early as the first half of XVIII century, did not believe in phlogiston, but that heat is a kind of motion of constituent particles within a body.

In his dissertation under the title "Some Reflections on the Cause of Heat and Cold," read 21 and 25 January 1745 at a session of the Russian Academy of Sciences, Lomonósov had two paragraphs which I translate and quote (B. N. Menshutkin. *Works of M. V. Lomonósov in physics and chemistry*. Moscow-Leningrad: Academy of Sciences of the USSR, 1936. Pp. 109, 110).

"A body A which acts upon a body B cannot add to the latter a greater velocity than that which it itself possesses. If, therefore, the body B is cold and immersed in a warm gaseous body A, the heat movement of the particles of the body A brings the particles of the body B into a heat movement, but it cannot induce in the particles of the body B a greater speed than that which is present in the particles of the body A. Therefore, the cold body B being immersed in the body A cannot perceive a greater degree of heat than that which the body A has."

". . . Furthermore, one cannot mention some definite velocity, a such one that someone else could not visualize mentally another, a greater velocity. This, of course, should be referred to the heat motion also: therefore, the highest and the last degree of heat is not a thinkable motion. *Vice versa*, the very same motion can decrease to such an extent that finally a body reaches a condition of an absolute rest—and no farther decrease in motion is possible. Consequently, by necessity, there should exist the greatest and the last degree of cold expressed in the complete rest of the particles, in the complete absence of their spinning movements."

In the first quotation Lomonósov expresses the Second Principle of Thermodynamics which was rediscovered and established 85 years later.

In the second he points out that there is no higher limit for temperature and gives an inference about the necessity for the lower limit of temperature—the absolute zero—a concept introduced into science about 1870, *i.e.* 125 years later. Even still further this self-made scientific genius goes: he defines the absolute zero as absence of the spinning movements of particles. Therefore Lomonósov's absolute zero temperature excludes even null-point energy due to the spin of electrons, and the theory of null-point energy based on Fermistatistics is a development of recent years; the measurement of temperature under zero null-point energy is yet among achievements of the future physics.

Paying this tribute I wish to reinstate that Miháilo Vasílievich Lomonósov developed his mechanical concept of heat in which an impossibility of heat transfer from a colder body to a warmer one, and the idea of the absolute zero temperature as a cessation of any kind of motion in or between the constituent particles of a body were incorporated far ahead of those scientists to which the discovery and the development of these two cornerstones of the contemporary thermodynamics were credited.

ANATOL J. SHNEIDEROV

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Science in the Albuquerque High School

I feel that Charles A. Gramet (*Science*, 1946, **103**, 149) has made some good suggestions as to how science enrollments might be increased in secondary schools. He feels that his own school system of Brooklyn, New York, gives a pretty good science education and that it need not feel inferior to challenges which come from colleges. I feel the same way about our schools, out here in the deserts of New Mexico.

I would like to make a few additional remarks about the nationwide decline in science enrollment in secondary schools. Here in our own school (Albuquerque High School) we require only one unit of science for graduation, anything taken above that is strictly on an elective basis. Back in 1930 I felt that such a requirement was inadequate but there seemed no way to promote additional requirements. Our school decided to go out and get the students, requirements or not. We could not use legal requirements, so we used other means to popularize the classes. These included advertising campaigns, an assembly or two, and a crew of physics students that carried scientific shows to our city and county grade schools.

The campaign bore fruit in a hurry. We believe now

that we boast one of the largest science enrollments, on a percentage basis, in the Nation. Our school has an enrollment of a little more than 2,100 students, 1,300 of whom take science. It is seldom that we graduate a person without more than two years of science. We have 240 students in our physics classes, and we have had that great a per cent (11.4) for about 12 years. If the student wishes, he can satisfy his science requirement by taking biology as a sophomore. Almost 700 take the subject each year, but in addition we seldom graduate a student who has not taken, in addition, one of the other laboratory sciences such as chemistry, physics, or our year course in geology.

We have not popularized our courses just by making them easy. On standardized tests we consistently beat the medians, even though we do carry along a few poor students. We believe that we have gained support by supplying good courses as well as advertising. We have done some pioneering also. In 1935 we started a full-year laboratory course in geology. In 1937 we started semester courses in radio physics, air navigation, and meteorology. These three courses were "shots in the dark," but they paid off in numerous fighter pilots, radio technicians, weather observers, and navigators in the war.

I am not sure that we would now welcome any rules requiring more than one science for graduation. We do not need it, and under our present plan we get people who want to take the subjects without other pressure. Our school has about every sort of outside activity imaginable, and the classroom has plenty of competition for students. We have gained our large enrollment by rowing upstream, and we sort of like it that way. We are ever on the lookout for ways to make our courses more attractive and more useful, and we hope to go on competing with whatever other attractions arise.

E. R. Harrington, *Head Science Department, The Albuquerque High School Albuquerque, New Mexico*

More Reversed Winter Flounders

In a recent article (*Science*, 1945, **102**, 672–673) E. W. Gudger described three specimens of "left-handed" winter flounders in some detail and stressed the rarity of their occurrence. Various members of the staff of the Atlantic Biological Station, St. Andrews, New Brunswick, have made similar observations in the Fundy area that may be of interest to readers of *Science*.

On 2 August 1945 a reversed specimen was brought to the station by the fisherman who took it the previous day on a trawl set in the St. Croix River, opposite Robinston, Maine. He apparently recognized the fish as being a winter flounder and stated that he had heard of such curiosities from other fishermen but had never seen one himself until then. This fish, a female, measured 369 mm. in total length, and 283 mm. to the end of the last vertebra. The numbers of fin rays, body proportions, and other characters conformed to the specific description given by Bigelow and Welsh (*Bull. U.S.B. Fisheries*, **40**, 472–507), and the fish appeared healthy and normal in all respects except for reversal.

Another reversed specimen of about the same size was on exhibit in the station museum, along with a normal one for comparison, for a number of years previous to the 1932 fire which destroyed the Biological Station.

Mr. E. G. Rigby, curator of the station, states that he has seen, in addition, several other specimens taken during the course of his 30 years service here. Dr. A. H. Leim, chief biologist, makes a similar report and refers to the capture of a "right-handed" specimen that was pigmented on both sides.

J. C. Medcof

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A Circular Slide Rule

Science, 1946, **103**, 113, describes a slide rule made by William E. Morrell for solving problems such as $d = \sqrt{x^2+y^2+z^2}$ and $r = \sqrt{x^2+y^2}$, etc., using a pair of linear scales and a pair of square-root scales which differ from those of the ordinary slide rule in that they are graduated according to the square root of numbers on the linear scales instead of the square root of numbers on a logarithmic scale.

If two identical scales are used, graduated so that they show square roots of numbers on a linear scale, the operation of finding the square root of the sum of two squares is done more simply than on the slide rule described. The problem is solved as simply as performing a multiplication on a pair of logarithmic scales.

The Rotarule, a circular slide rule manufactured by this writer, has carried such a pair of square root scales since 1927, as well as a linear scale making it possible to solve $r = \sqrt{x^2+y^2}$ and $c = a^2 + b^2$ with a minimum of effort.

J. R. Dempster

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Reply to Prof. Chamberlain

Some years ago it was seriously propounded that all scientific research be banned in order to permit the world to catch up. All that would happen, of course, would be that we ourselves would remain stagnant, and the rest of the world would go ahead. Some such thought as this is suggested as a result of the reading of Prof. Katherine Chamberlain's article on "Another chain reaction" (*Science*, 1946, **103**, 158–160), in which she suggests that all atomic bomb research be abandoned until a definite world understanding is reached regarding the use of this most powerful form of energy. I would suggest instead that the research be stepped up to double its present rate. Power is a force for good when used in the right hands, and right today we need some organization of the good forces, as Prof. Chamberlain indicates. The time is fast approaching when those who, in a democracy, do not take an active interest in public affairs will be deemed negligent.

Robert Kerr Dewar, M.D.

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Book Reviews

Two-way radio. Samuel Freedman. Chicago–New York: Ziff-Davis, 1946. Pp. xxii + 506. (Illustrated.) $5.00.

This book treats of systems for two-way radio—that is, of systems for communicating between a fixed station and a mobile unit or between two mobile units. For this purpose both a transmitter and a receiver are necessary at each point.

The purpose of the book is to make clear the considerations which determine the choice of any particular system and to describe the necessary apparatus and its installation. The long experience of the author in microwave development and in the development of systems for ship and submarine communication and for police patrol enables him to speak with authority on the solution of such problems.

The book is not intended as a text on communications theory. Some small space, it is true, is devoted to an introduction to electric circuit theory and the propagation of electric waves, but the treatment is necessarily somewhat superficial. An occasional electronic circuit diagram appears, but no attempt is made to analyze its parts or to discuss its operation. The scope of the book is essentially general and descriptive, and the treatment of the central theme is thorough and masterly.

In the earlier chapters attention is paid to available power sources, types of antennae, and details of apparatus, both at the fixed and the mobile station. Chapters follow which deal clearly and exhaustively with the relative advantages and limitations of amplitude modulation, frequency modulation, induction and guided carrier systems, and possible future applications of microwaves to two-way radio. These chapters are particularly well done.

More than a hundred pages of the book are on two-way radio for railroads. In this discussion, considerable attention is paid to the arguments for and against the adoption of radio in place of visual signals. The author makes a strong case for radio as a supplementary and powerful auxiliary to the visual signal system, and considers at length the choice of radio systems applicable to the various complex problems of railroad operation.

The remaining shorter chapters on police, fire, and forestry systems, highway and public transport services, and marine and aeronautical applications deal with the special problems inherent in these services and not previously covered.

The book is well furnished with cuts of commercial apparatus and pictures of actual installations. The commercial aspects are not, however, unduly emphasized.

This is a mine of detailed information and should prove of value, not only as an aid in planning new projects but in furthering the application of radio in fields where its usefulness is just beginning to be appreciated.

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Sequential analysis of statistical data: applications. (Prepared by Statistical Research Group, Columbia Univ. for Applied Mathematics Panel, NDRC.) New York: Columbia Univ. Press, 1945. 6 sections & appendices. $6.25.

The procedure of sequential analysis is as follows: An item is drawn from the lot to be inspected, and it is inspected; on the basis of the evidence of the sample of one, (a) the lot is accepted, (b) the lot is rejected, or (c) the evidence is found to be insufficient for either decision. If decision (c) is reached, a second item is drawn and inspected, and on the basis of the sample, now of two items, the same three possible decisions are considered. This procedure is followed until the evidence of the sample is sufficient to warrant (a) or (b). Thus, inspection is continued until the cumulated evidence is sufficiently strong, one way or the other, for the inspector to call the lot acceptable or unacceptable. "Sufficiently strong" is made determinant by specifying acceptable risks of making incorrect decisions.

By this procedure, conspicuously good lots are quickly accepted, conspicuously bad lots are quickly rejected, and extensive inspection is needed chiefly by lots of doubtful quality, greatly increasing thereby the efficiency, and reducing the cost, of acceptance inspection. Mathematical analysis indicates that sequential analysis may yield a savings frequently greater than 50 per cent.

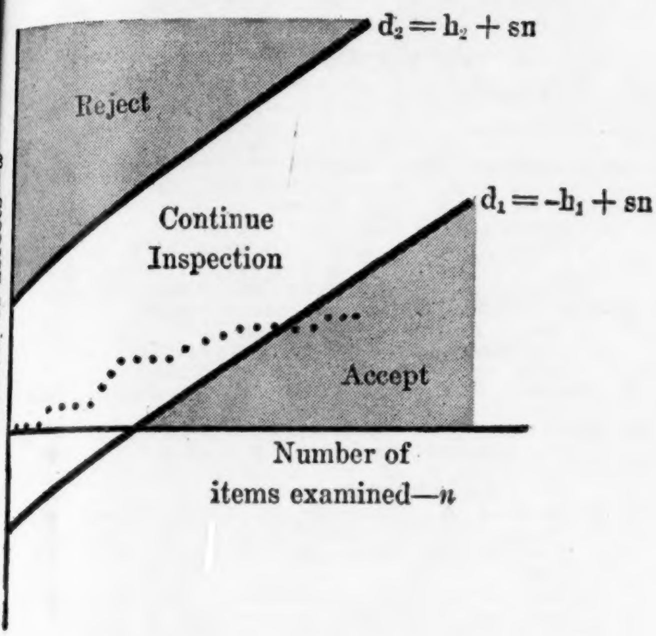
These studies make fascinating reading for those who have not been permitted, because of wartime secrecy, to follow the new developments in sequential analysis that occurred during the War. A beguiling and stimulating procedure has been devised that would seem to guarantee exciting vistas as one contemplates possible applications of great practical importance, such applications already having been extensively made by the various branches of the armed forces. The same procedure, modified to suit the problem, can be applied to reduce the cost of sampling analysis in connection with experimental work, presumably both in agriculture and in industry; and it can be applied to a series of multiple samples as well as to a sequence of observations.

While considerable mathematical patience is required to comprehend rigorous demonstration of the procedure, the intuitive explanation can be grasped by anyone trained in the fundamentals of the modern theory of sampling.

The procedure devised is such that a table can be drawn up; or an acceptance inspection chart, almost identical in form for a variety of problems, can be set up as a standard procedure. This chart is as simple in form and as broad in application as the widely used quality-control chart.

When this chart has been constructed, the procedure consists simply of the sequential plotting against n (number of items examined) of the number of defects observed, d, for which the vertical scale is used. This

Acceptance Inspection Chart



is continued until the plotted line runs either into the area of acceptance or into that of rejection. The dotted line in the figure shows how a set of results would lead, for example, to acceptance.

The equations for the two lines that mark the margins of acceptance and of rejection are derived from the following set of inequalities:

B.14
$$\frac{p_2^d(1-p_2)^{n-d}}{p_1^d(1-p_1)^{n-d}} \begin{cases} \geqq A & \text{Accept } p = p_2 \\ \leqq B & \text{Accept } p = p_1 \\ < A \text{ and } > B & \text{reserve judgment, take additional observation} \end{cases}$$

By taking logarithms, this becomes

B.15
$$d \log \frac{p_2}{p_1} - (n-d) \log \frac{1-p_1}{1-p_2} \begin{cases} \geqq a \\ \leqq b \\ < a \text{ and } > -b \end{cases}$$

in which $a = \log A$ and $b = \log B$.

From the first inequality in B.15, the marginal line is obtained by $d_1 = -h_1 + sn$; from the second inequality in B.15, the marginal line is obtained by $d_2 = h_2 + sn$. In these, s, h_1, and h_2 are parameters dependent on p_1, p_2, α and β.

In the inequalities, A and B (for which a and b are the logarithms) are so determined that, if H_1 is true, the probability will be α, or less, that H_2 will be accepted; and so that, if H_2 is true, the probability will be β, or less, that H_1 will be accepted. Thus, whenever H_2 is accepted, $p_2 \geqq Ap_1$ and the total probability of obtaining a sample that will lead to the acceptance of H_2 is at least A times as large when H_2 is true as when

H_1 is true. Now α is by definition the probability of accepting H_2 when H_1 is true; and $1-\beta$ is, by definition of β, the probability of accepting H_2 when H_2 is true. Thus, A must be so set that $1-\beta \geqq A\alpha$. From this the approximation follows that $A \doteq \frac{1-\beta}{\alpha}$. (An exact analysis of the discontinuities would permit a slightly smaller a; the use of a somewhat too large a has the effect of reducing the risks of error slightly below α and β.) By a similar line of reasoning, $B \doteq \frac{\beta}{1-\alpha}$, so that $a \doteq \log\frac{1-\beta}{\alpha}$ and $b \doteq \log\frac{\beta}{1-\alpha}$.

Tables are provided for obtaining values of a and b for selected values of α and β ranging from .001 to .40 Tables are also provided for finding the values of s, h_1, and h_2; these values can also be found by using the nomographs devised for that purpose. They are determined by the values of α, β, p_1 and p_2, which are fixed for the problem in hand. The acceptable quality limit is p_1; the unacceptable quality limit is p_2; α is the maximum risk or probability of rejecting lots of quality p_1 or better; and β is the maximum risk or probability of accepting lots of quality p_2 or worse.

Three other tools of analysis are supplied in the procedure: the operating characteristic (OC) curve, the average outgoing quality (AOQ) curve, and the average sample number (ASN) curve. The OC curve shows the relationship between the probability of accepting a lot and the true quality (fraction defective) of the lot. For most sampling plans it is unnecessary to construct these curves; but it is important to compute the average sample number for $p=p_1$ and $p=p_2$. Thus, in one of the problems illustrated the authors found $\bar{n}_{p_1}=63$ and $\bar{n}_{p_2}=61$. It could be assumed from these values that on the average the decision to accept or reject would be reached by the time 61–63 observations had been made. In the problem illustrated the decision was reached at the fifty-third observation. Being able to tell in advance approximately how large a sequential number of observations will be required to reach a decision is certainly an important advantage of the method.

Criticism is rampant on the question of acceptance sampling, but for the most part it deals with the validity of the tests, the relationship of the test to expected performance, the randomness of the samples, etc. However fine a method of analysis may be, it will remain impractical unless the data analyzed are suitable and in conformance with the assumptions involved in the method. Nevertheless, that criticism cannot detract from the importance of the contribution made by those who have developed the method of sequential analysis. The method is neatly and ingeniously contrived, and it is surprisingly simple in application as far as the primary requirements of any particular problem are concerned.

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War on Weeds

(*Continued from p. 468.*)

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